ABSTRACT

PALAPARTHY, KALYAN AADITYA HAYAGREEVA. Simulative Evaluation of HVAC Problems in Building ‘C’ at Brunswick Community College using Carrier HAP 4.5. (Under the direction of Dr. Herbert M Eckerlin and Dr. Stephen D Terry).

The study commences with a discussion on the feasibility of using the DOE 2 program ‘EnergyPlus’ for the energy modeling of Building “C” at Brunswick Community College, Bolivia, NC. It further proceeds to exemplify reasons for selecting and using the HVAC modeling program Carrier HAP 4.5 using a case study on the TV Studios at Bryan Center at UNC – TV, Chapel Hill, NC. Finally a study on the effect of maintaining positive, negative and no pressure difference between the interior of the building and the ambient conditions is performed using Carrier HAP 4.5.

This study was performed to address the discomfort caused by the humidity and temperatures in certain areas of the Building “C” and the inefficiency of its energy performance. As a result of this study, it was observed that the discomfort caused was primarily due to the under-sizing of the HVAC system that is currently serving the Classroom Building. It was also observed that the variations in relative pressurization of the building affected the energy performance up to 0.59% in terms of annual cost with costs first increasing from positive pressurization to no pressurization and then decreasing to negative pressurization. A comparison with the actual design system obtained from the original plans was also performed. Finally a system as suggested by the software, with comfort conditions as parameters, was included in the comparison. It was observed that the use of this system increased the annual operation cost by 4.15% as compared to the current system while providing the required comfort conditions.

Simulative Evaluation of HVAC Problems in Building 'C' at Brunswick Community College using Carrier HAP 4.5

by
Kalyan Aaditya Hayagreeva Palaparthy

A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the degree of
Master of Science

Mechanical Engineering

Raleigh, North Carolina

2011

APPROVED BY:

____

Dr. Herbert M Eckerlin
Committee Co-Chair

____

Dr. Stephen D Terry
Committee Co-Chair

____

Dr. James W Leach
Committee Member

DEDICATION

I would like to dedicate this work to my parents, my family, my teachers, my friends and GOD.

BIOGRAPHY

The author was born on 16th of October 1986 to Mr. Sesha Sai Prasad Palaparthy and Mrs. Rajeswari Palaparthy in New Delhi, India. He received his primary education till fifth grade in Ramjas Public School, R.K.Puram, New Delhi. Then, he along with his family moved to Hyderabad, Andhra Pradesh in Southern India. He continued pursuing his secondary education at The Hyderabad Public School, Ramanthapur, Hyderabad. He was the topper of his School in the 10th grade nationwide board exams. His keen interest in Mathematics, Physics and Chemistry led him to pursue his Higher Education in these fields in New Generation Jr. College under the Board of Intermediate Education, Hyderabad. His inclination towards application of scientific principles in daily life and acumen in principles of energy led him to pursue Mechanical Engineering. He completed his Baccalaureate in Mechanical Engineering from M.V.S.R. Engineering College, Osmania University, Hyderabad. He was the University Topper and a Gold Medalist for all the four years of his under graduation. The desire to acquire an in depth knowledge, have a greater practical exposure and hands on experience in the Thermal and Fluid Sciences led him to pursue his Masters in Mechanical Engineering at North Carolina State University. He joined the Industrial Assessment Center (IAC) at NCSU in December 2010 and has been gaining a plethora of experience and knowledge in the areas of his interest.

ACKNOWLEDGMENTS

I would like to thank my advisor Dr. Herbert M Eckerlin and my graduate committee's co-chair Dr. Stephen D Terry for their patience in answering to every one of my inquiry to the greatest detail possible. I am eternally grateful to them for the wealth of knowledge they shared with me and all the support they provided to make this work possible.

I would like to thank Dr. James W Leach, who readily accepted my request to be a member of my graduate committee and imparted me with a spirit of confidence when he expressed his interest to learn something new from me.

I am grateful to Mr. Doug Gunnel who participated in the visits to the site along with us and shared his expertise and data with us.

I would also like to thank my lab mates William Buescher, Ryan Nester, David Hunt, Walter Bright, Blake Chestnut, Andrew Murphy, Lynn Albers, Saurabh Ray and Kate Patterson who were always there for me for both conceptual and moral support throughout my work at the IAC.

Last but not the least, I would like to thank all the maintenance personnel (especially Ms. Donna Baxter) at the buildings under consideration for sharing every piece of information that they possessed and could get their hands on, upon our request.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

Following is a list of abbreviations that are used in this work.

(a) HVAC: Heating Ventilation and Air Conditioning

(b) CFM: Cubic Feet per Minute

(c) AHU: Air Handling Units

(d) OA: Outside Air

(e) SA: Supply Air

(f) CHW: Chilled Water

(g) db: Dry Bulb

(h) wb: Wet Bulb

(i) RH: Relative Humidity

(j) CAV: Constant Air Volume

(k) VAV: Variable Air Volume

(l) ACH: Air Changes per Hour

(m) ADP: Apparatus Dew Point

(n) HAP 4.5: Hourly Accounting Program 4.5

CHAPTER 1: INTRODUCTION

1.1 BUILDING AND SYSTEM DESCRIPTION

Brunswick Community College; a tax-supported, public, nonprofit school in Bolivia, North Carolina, was established by the North Carolina Legislature in July 1979 under provisions of the General Statutes of North Carolina, Chapter 115-A, passed by the Legislature in 1963. It is operated by the North Carolina Community College System and the North Carolina State Board of Community Colleges. Brunswick Community College was chartered as Brunswick Technical Institute. On May 1, 1979, the General Assembly passed a bill to permit technical institutes to change their names to technical colleges with the approval of the Board of Trustees and the Brunswick County Board of Commissioners. On October 5, 1979, the Board of Trustees, with the approval of the Brunswick County Board of Commissioners, voted unanimously to change the name of the institution to Brunswick Technical College. The College received its initial accreditation from the Southern Association of Colleges and Schools in 1983. In 1988, the name of the College was changed to Brunswick Community College to reflect statewide changes in community colleges.

The building under consideration for analysis is the Classroom Building (Building C) at Brunswick Community College which is a two story building with a total floor area of 31,592 ft^2. The building consists of 85 spaces of which 73 spaces are conditioned (as observed from the conditioned air ductwork plans). Thus, the construction plans of the

building indicate a conditioned area of 26,268 ft^2. The elevation plan shows the average height of each floor to be approximately 13 ft.

Figure 1.1: Brunswick Community College 'Building C'

The construction plans reveal the following details:

Wall Construction
Outside
4" Brick
1" Air Gap
1" Styrofoam Insulation
8" Masonary Block
1" Air Gap
1/2" Gypsum Board on Met Furring 16 O.C.
Inside

Roof Construction
Outside
Elastomeric Coating
Sure Seal MMB Roof System on Rigid Insulation
1/2" Gypsum Board
Inside

Floor Construction
Inside
4" Concrete Slab Reinf. W/6x6 10/10 W.W.M
1" Perimeter Insulation
Vapor Barrier
4" Gravel
Ground

Interior Ceiling Construction
2nd Floor
4" Concrete Slab Reinf. W/6x6 10/10 W.W.M
1st Floor

Figure 1.2: Construction Details of Building C

The chiller serving the building was manufactured by Carrier and has a capacity of 100 tons. It has two circuits, each with two reciprocating compressors. The water leaves the chiller at 46^{O}F and 267 GPM. The condenser is air cooled with air entering at 95^{O}F at a rate of 78,400 CFM at design conditions. The chiller is stationed on the south west end of the building just outside the Mechanical Equipment room (Room No. 140).

Figure 1.3: Chiller serving Building C

The main boiler serving the building, manufactured by Burnham, is a forced draft steam boiler that fires on No.2 Oil. The furnace surrounds the flame with highly efficient water backed primary heat-absorbing surfaces. This large combustion chamber is easy to fire, accommodating many forced-draft burners without flame impingement or other critical firing

problems. Forced-draft firing makes the 4F inherently more efficient than boilers using outmoded atmospheric burners, and gives the option of burning gas or oil.

4F - 45 Boiler Models	78
Gross Output MBH BHP Lbs. Stm/Hr	 579 17.3 597
Net Rating - Steam MBH Sq. Ft.	 449 1,870
Net Rating - Water MBH	504
Firing Rate - Gas MBH Firing Rate - Light Oil GPH Heavy Oil GPH	724 5.2 —
Heating Surface Sq. Ft. Fireside Waterside	 73 78
Furnace Volume Cu. Ft.	10.7
Heat Release MBH/Cu. Ft.	67.7
Water Content Gal. Steam Water	 81 112
Approx. Dry Weight Lbs.	1,900
Approx. Full Weight Lbs. Steam Water	 2,570 2,835

Figure 1.4: Boiler running on No. 2 Fuel Oil and its Specifications

Another oil fired water heater also serves the building. The specifications of this heater are as follows.

State Titan Power Gas Commercial Oil Fired Water Heater				
MODEL	AFG	MAX INPUT	2.25 gals per hour	
INPUT BTUH		315,000	CAPACITY	84.0 US Gal
RECOVERY		263.45 gal/hr	PRESSURE	160 psi

Figure 1.5: Specifications of Oil Fired Water Heater

Figure 1.6: Oil Fired Water Heater

The electrical plans show that the building consists of a Cosmetology lab that is used for teaching students to wash, cut and style hair. It has around 117 kW of rated plug load, but a majority of it is used for operations involving heating water and other fluids which go down the drain and do not significantly contribute to the cooling load on the HVAC system.

The HVAC system serving the building consists of 18 Carrier Air Handling Units (AHUs). The configuration of AHUs is such that the heating coils are located in front of the cooling coils in order to prevent freezing of cooling coils.

Figure 1.7: One of the 18 Air Handling Units

The fresh air makeup ducts are relatively small (i.e., 6 x 8 inch) when compared to the return air ducts and are not fan pressurized. The return air ducts do not reject any air to the atmosphere. They just transfer the return air to the mechanical rooms and are driven by the relatively lower pressurization of these rooms. Automatic control dampers are installed in the makeup air ducts. The building is not equipped with an economizer cycle.

The HVAC Control system consists of 3-way valves on the chilled water and hot water lines which were installed by T.A.Woods (HVAC Company) in 2004. Both the chilled water and hot water circuits in this system have constant flows.

1.2 INTRODUCTION TO ‘EnergyPlus’

1.2.1 What is ‘EnergyPlus’?

EnergyPlus is a simulation program designed for modeling buildings with all their associated heating, ventilating, and air conditioning equipment. EnergyPlus is a simulation engine: it was designed to be an element within a system of programs that would include a graphical user interface to describe the building. However, it can be run standalone without such an interface.

Like all simulation programs, EnergyPlus consists of more than just an executable file. EnergyPlus needs various input files that describe the building to be modeled and the environment surrounding it. The program produces several output files, which need to be described or further processed in order to make sense of the results of the simulation. Finally, even in stand-alone mode, EnergyPlus is usually not executed “by hand”, but rather by running a procedure file which takes care of finding input files and storing or further processing the output files.

1.2.2 Overall scheme/methodology for running ‘EnergyPlus’

<u>Step 1: Planning Ahead</u>

EnergyPlus requires some information in specified, externally available formats; other information may require some lead time to obtain. The following checklist should be completed before starting to construct the input file.

(a) Obtaining the location and design climate information for the city in which the building is located. If possible, using one of the weather files available for the weather period run.

(b) Obtaining sufficient building construction information to allow specification of overall building geometry and surface constructions (including exterior walls, interior walls, partitions, floors, ceilings, roofs, windows and doors).

(c) Obtaining sufficient building use information to allow specification of the lighting and other equipment (e.g. electric, gas, etc.) and the number of people in each area of the building.

(d) Obtaining sufficient building thermostatic control information to allow specification of the temperature control strategy for each area of the building.

(e) Obtaining sufficient HVAC operation information to allow specification and scheduling of the fan systems.

(f) Obtaining sufficient central plant information to allow specification and scheduling of the boilers, chillers and other plant equipment.

<u>Step 2: "Zone" the Building</u>

A building "surface" is the fundamental element in the building model. In the general sense, there are two types of "surfaces" in EnergyPlus. These are

(a) Heat Transfer Surfaces

(b) Heat Storage Surfaces

The first rule of building modeling is, "Always define a surface as a heat storage surface unless it must be defined as a heat transfer surface". Any surface, which is expected to separate spaces of significantly different temperatures, must be defined as a heat transfer surface. Thus, exterior surfaces, such as outside walls, roofs and floors, are heat transfer surfaces. Interior surfaces (partitions) are heat storage surfaces if they separate spaces maintained at the same temperature and heat transfer surfaces if they separate spaces maintained at different temperatures. In order to correctly "zone" the building it is necessary only to distinguish between the two.

A "zone" is a thermal, not a geometric, concept. A “zone” is an air volume which is at a uniform temperature plus all the heat transfer and heat storage surfaces bounding or inside of that air volume. EnergyPlus calculates the energy required to maintain each zone at a specified temperature for each hour of the day. Since EnergyPlus performs a zone heat balance, the first step in preparing a building description is to break the building into zones.
An inexperienced building modeler may be tempted to define each room in the building as a zone, but the thermal zone is defined as a volume of air at a uniform temperature. The general rule then is to use the number of fan systems (and radiant systems) not the number of rooms to determine the number of zones in the building. The minimum number of zones in a general simulation model will usually be equal to the number of systems serving the building. The collection of heat transfer and heat storage surfaces defined within each zone will include all surfaces bounding or inside of the space conditioned by the system.

Step 3: Prepare to Construct the Building Model

It is recommended that the engineer sketch the building with its zones. Surface dimensions should be included in the sketch. Additional geometric and surface information is required before an input file describing the building can be constructed. Specifically the building model must:

(a) Determine heat transfer and heat storage surfaces: The surfaces of the building can be described in any order; grouping surfaces by zone may help read the input file. Specifics of the describing surfaces help categorize the surface's heat transfer/storage as well as identify the surface construction information. The subsurfaces (windows, doors) on the base surfaces will inherit the base surface properties.

Surfaces that specify "themselves" as the outside boundary condition are ceilings, floors and partitions that divide temperature-controlled spaces. The program assumes that the surface temperatures on both sides of the surface are the same. This means that even though heat may be stored in a partition, ceiling, or floor, no heat flows through it.

Some surfaces divide the temperature controlled space from the outside environment. Surfaces that are both sun and wind exposed (e.g. exterior walls, exposed floors, roofs) feel the full effect of both solar radiation and outside temperature, and the outside air film resistance for these surfaces changes with wind speed and wind direction. Surfaces that are not sun or wind exposed (a wall to an "uncontrolled" space) are not affected by solar

radiation, wind speed or direction and have a constant outside convective air film resistance.

Surfaces such as basement walls and slab floors separate the space from the earth surrounding the surfaces. Therefore, the outside surface temperatures become the ground temperatures.

Other surfaces separate zones that may be at different temperatures. These surface types allow heat transfer (by conduction through the walls) from a zone at a higher temperature to a zone at a lower temperature. The location of the heat storage surface in the zone is not important except in specialized solar studies. The surface above (wall to uncontrolled space) would be more correctly modeled as an inter-zone surface.

(b) <u>Define equivalent surfaces</u>: Now the objective is to define as few surfaces as possible without significantly compromising the integrity of the simulation. We reduce the number and complexity of surfaces in our input file by defining equivalent surfaces.

For purposes of the heat transfer calculations, a geometrically correct rendering of the zone surfaces is not required. The surfaces do not even have to be connected. As long as the program knows to which thermal zone (mass of air) each surface transfers heat, it will calculate all heat balances correctly. The goal is to seek an adequate level of detail to

capture the key features of the building envelope without spending excess time describing and computing results for details that are insignificant.

(1) Define all roofs and floors as rectangles regardless of the shape of the zone. Each zone may have one rectangular roof and one rectangular floor of a given construction.

(2) Define all heat storage surfaces of the same construction within a zone as a single surface. The size of the single surface is obtained by summing the individual surface areas exposed to the zone. Thus, if a partition is completely within a zone (both sides of the partition are exposed to the zone), the area of each side must be added to the area of the equivalent surface. On the other hand, if the partition separates two zones, the area of only one side should be added to the equivalent surface.

(3) Combine all windows on a given exterior surface into a single window. Usually each exterior surface should have only one window of each type. Overhangs or other shading devices may require that more windows be specified or combined together.

(c) <u>Specify surfaces and subsurfaces (windows, doors, etc.) construction and materials</u>: BLAST, DOE-2 and other programs often have "libraries" of constructions, schedules, and other aspects of simulating the building. In EnergyPlus, a special set of files in the Data Sets folder represent many facets of building simulation. Data sets are usually IDF snippets or macro files. For example, in case of constructions, the file 'ASHRAE_2005_HOF_Materials.idf' (which uses guidelines from the ASHRAE

Handbook of Fundamentals, 2005) contains materials and constructions from Chapters 30 and 25 of the Handbook. Since Chapter 30 discusses heating and cooling loads, it includes constructions for light, medium and heavy weight buildings – these constructions are represented in the dataset file.

(d) Compile surface and subsurface information:

(1) Building information:

Building North Axis: This syntax simplifies building geometry specification by designating one wall of the building as the building's north pointing axis. The building model North axis is measured from true (compass) North. Surface facing angles (see surface information below) are then specified relative to the building north axis.

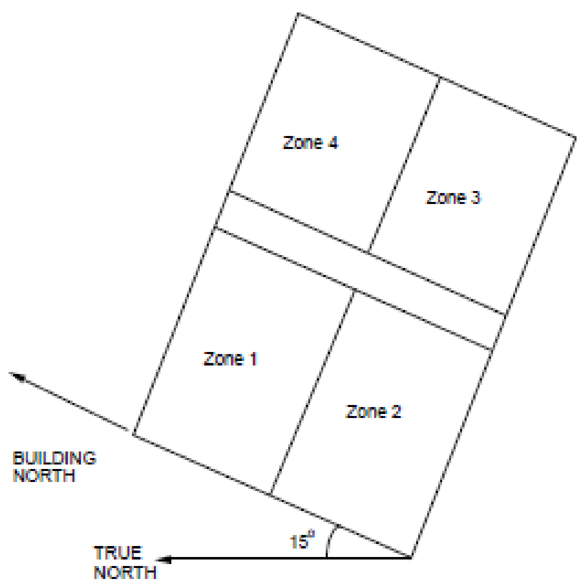


Figure 1.8: Building North Axis Illustration

(2) Zone information:

Wall height: In a simple model, one should make all the walls the same height. Then, the simple, one zone model can entirely enclose the space. In more complex models, we may resize each wall accordingly.

(3) Surface information:

(i) Base Surface Type: Heat Transfer/Heat Storage Surfaces may be of the following types: wall, floor, roof, internal mass, or subsurface

(ii) Construction: The type of construction of the surface. Subsurface information:

a. Subsurfaces are Windows, Doors or Glass Doors

b. Area: Area of the subsurface.

c. Reveal: For windows only, the distance it is inset from the outside surface of a wall. For simplicity, put all the windows in the same physical plane as the wall they are on. The surfaces are numbered counter-clockwise around the zone beginning at the lower left corner of the figure. A few simple conventions should be followed to facilitate the construction of zone information tables:

1. Number all surfaces in order counter-clockwise around the zone.

2. Keep the subsurfaces with the base surface on which they are located.

3. Specify lengths for base surfaces and areas for subsurfaces and internal mass.

4. Specify the roof and floor as rectangles of the correct size.

Step 4: Compile Internal Space Gain Data

People, lights, equipment, outside air infiltration and ventilation all constitute "internal gains" for the thermal zone. These gains are described to EnergyPlus as a design or peak level with a schedule that specifies a fraction of the peak for each hour. The peak level is calculated by the user.

1.2.3 Other useful programs/information

HVAC Template Objects: HVAC Template objects are available. These are intended to allow for several “usual” HVAC types to be expanded into EnergyPlus HVAC inputs with minimal user entries. These are described in the “Input/Output Reference” document under the Group “HVAC Templates” and the expansion process is described in the Auxiliary Programs document under “Expand Objects”.

DataSets: EnergyPlus uses snippets of IDF files to create the library of data that may be useful. Two folders are created upon installation: DataSets – which contains IDF snippets and MacroDataSets – which also contain IDF snippets but are in a form such that they can be easily used with the EPMacro program.

Slab and Basement Programs: The Slab and Basement programs can be used to create accurate Ground Temperature profiles for our runs using minimal input about our building. These are used prior to an actual simulation.

Coefficient Curve Generation: The CoeffConv and CoeffConv utility programs can be used to convert DOE-2 temperature dependent curves (Fahrenheit) to EnergyPlus temperature curves (Centigrade/Celsius).

WeatherData: The E/E+ format is very flexible (as well as being ASCII and somewhat readable). In addition to the usual weather data (temperatures, solar radiation data), the format embodies other information from the location and weather data (e.g. design conditions, calculated ground temperatures, typical and extreme weather periods). The web site for EnergyPlus (http://www.energyplus.gov) provides downloadable weather data for many sites throughout the world from several different formats.

Results Processing: Results from EnergyPlus (using EP-Launch) appear in several possible formats. The most basic are the csv files for the time oriented output and the meter output. These will appear as <filename>.csv and <filename>Meter.csv. These can be quite detailed files (ref: Output:Variable, Output:Meter commands). Other formats (such as Tabular outputs) can yield more summarized results.

HVAC-Diagram: Another post processing program (EnergyPlus versions 1.2 and later) is the HVAC-Diagram application. It reads one of the EnergyPlus output files (eplusout.bnd) and produces a Scalable Vector Graphics (SVG) file.

CSVProc: This simple post processing program uses .csv files (such as created by ReadVarsESO) and performs some simple statistics on the contents.

convertESOMTR: This simple post processing program can be used seamlessly with EP-Launch to provide IP unit output files rather than SI units.

DataFiles: Some example files are installed during installation (Sample Files option). Each sample input file should contain comments about its purpose at the start of the file. Other example files are made available from the website (http://www.energyplus.gov/).

Library Files: Library files for EnergyPlus are embodied in the DataSets and MacroDataSets folders. DataSets are IDF excerpts – we must cut and paste from them in order to use them. Items in MacroDataSets can be used in conjunction with the EPMacro preprocessor program. All files are in the necessary form for processing with EnergyPlus.

1.3 INTRODUCTION TO ‘Carrier Hourly Analysis Program 4.5’

1.3.1 About Hourly Analysis Program

Carrier’s Hourly Analysis Program (HAP) is a computer tool which assists engineers in designing HVAC systems for commercial buildings. HAP is two tools in one. First it is a tool for estimating loads and designing systems. Second, it is a tool for simulating building energy use and calculating energy costs. In this capacity it is useful for LEED®, schematic design and detailed design energy cost evaluations. HAP uses the ASHRAE-endorsed transfer function method for load calculations and detailed 8,760 hour by hour simulation techniques for the energy analysis. This program is released as two separate, but similar products. The “HAP System Design Load” program provides system design and load estimating features. The full “HAP” program provides the same system design capabilities plus energy analysis features.

1.3.2 HAP System Design Features

HAP estimates design cooling and heating loads for commercial buildings in order to determine required sizes for HVAC system components. Ultimately, the program provides information needed for selecting and specifying equipment. Specifically, it:

(a) Calculates design cooling and heating loads for spaces, zones, and coils in the HVAC system.

(b) Determines required airflow rates for spaces, zones and the system.

(c) Sizes cooling coils, heating coils, air circulation fans, chillers and boilers.

1.3.3 HAP Energy Analysis Features

HAP estimates annual energy use and energy costs for HVAC and non-HVAC energy consuming systems in a building by simulating building operation for each of the 8,760 hours in a year. Results of the energy analysis are used to compare the energy use and energy costs of alternate HVAC system designs so the best design can be chosen. Specifically, HAP performs the following tasks during an energy analysis:

(a) Simulates hour-by-hour operation of all heating and air conditioning systems in the building.

(b) Simulates hour-by-hour operation of all plant equipment in the building.

(c) Simulates hour-by-hour operation of non-HVAC systems including lighting and appliances.

(d) Uses results of the hour-by-hour simulations to calculate total annual energy use and energy costs. Costs are calculated using actual utility rate features such as stepped, time-of-day and demand charges, if specified.

(e) Generates tabular and graphical reports of hourly, daily, monthly and annual data.

1.3.4 Using HAP to design Systems and Plants

All design work requires the same general five step procedure:

(a) <u>Define the Problem</u>: First define the scope and objectives of the design analysis. For example, what type of building is involved? What type of systems and equipment are required? What special requirements will influence system features?

(b) Gather Data: Before design calculations can be performed, information about the building, its environment and its HVAC equipment must be gathered. This step involves extracting data from building plans, evaluating building usage and studying HVAC system needs. Specific types of information needed include:

(1) Climate data for the building site.

(2) Construction material data for walls, roofs, windows, doors, exterior shading devices and floors, and for interior partitions between conditioned and non-conditioned regions.

(3) Building size and layout data including wall, roof, window, door and floor areas, exposure orientations and external shading features.

(4) Internal load characteristics determined by levels and schedules for occupancy, lighting systems, office equipment, appliances and machinery within the building.

(5) Data concerning HVAC equipment, controls and components to be used.

(c) Enter Data into HAP: Next, use HAP to enter climate, building and HVAC equipment data. When using HAP, our base of operation is the main program window. From the main program window, first create a new project or open an existing project. Then we define the following types of data which are needed for system design work:

(1) Enter Weather Data: Weather data defines the temperature, humidity and solar radiation conditions the building encounters during the course of a year. These conditions play an important role in influencing loads and system operation. To

define weather data, a city can be chosen from the program's weather database, or weather parameters can be directly entered. Weather data is entered using the weather input form.

(2) Enter Space Data: A space is a region of the building comprised of one or more heat flow elements and served by one or more air distribution terminals. Usually a space represents a single room. However, the definition of a space is flexible. For some applications, it is more efficient for a space to represent a group of rooms or even an entire building. To define a space, all elements which affect heat flow in the space must be described. Elements include walls, windows, doors, roofs, skylights, floors, occupants, lighting, electrical equipment, miscellaneous heat sources, infiltration, and partitions. While defining a space, information about the construction of walls, roofs, windows, doors and external shading devices is needed and so is the information about the hourly schedules for internal heat gains. This construction and schedule data can be specified directly from the space input form (via links to the construction and schedule forms), or alternately can be defined prior to entering space data. Space information is stored in the project database and is later linked to zones in an air system.

(3) Enter Air System Data: An Air System is the equipment and controls used to provide cooling and heating to a region of a building. An air system serves one or more

zones. Zones are groups of spaces having a single thermostatic control. Examples of systems include central station air handlers, packaged rooftop units, packaged vertical units, split systems, packaged DX fan coils, hydronic fan coils and water source heat pumps. In all cases, the air system also includes associated ductwork, supply terminals and controls. To define an air system, the components, controls and zones associated with the system must be defined as well as the system sizing criteria. This data is entered on the air system input form.

(4) Enter Plant Data: A Plant is the equipment and controls used to provide cooling or heating to coils in one or more air systems. Examples include chiller plants, hot water boiler plants and steam boiler plants. This step is optional; it is only required if we are sizing chiller or boiler plants. To define a plant for design purposes, the type of plant and the air systems it serves must be defined. This data is entered on the plant input form.

(d) <u>Use HAP to Generate Design Reports</u>: Once weather, space, air system and plant data has been entered, HAP can be used to generate system and plant design reports. If calculations are needed to supply data for these reports, the program will automatically run the calculations before generating the reports. If all the data needed for the reports already exists, reports are generated immediately.

(e) Select Equipment: Finally, we use data from the reports that are generated to select the appropriate cooling and heating equipment from product catalogs or electronic catalog software. System and plant design reports provide information necessary to select all the components of our HVAC system including air handlers, packaged equipment, supply terminals, duct systems, piping systems and plant equipment.

1.3.5 Using HAP to estimate Energy Use and Cost

HAP is designed with features to help us efficiently compare energy costs of HVAC design alternatives both in the preliminary design phase of a project and in the detailed design phase of a project:

(a) In the Preliminary or Schematic Design Phase of a project a variety of HVAC designs and equipment types may be under consideration. The goal of energy analysis in this phase of a project is to quickly compare the energy cost performance of many design alternatives to identify a small group of designs with the best performance for further, more detailed study. Simplification and approximation may be appropriate here both because of limited information about the building and because speed is important in evaluating the alternatives. The HAP Wizard interface is designed to help us quickly perform these types of energy analysis.

(b) In the Detailed Design Phase of a project one or a small set of HVAC designs is under consideration. The goal of energy analysis in this phase of a project is to carefully

analyze and optimize the design. The goals here may also include generating documentation for LEED Energy and Atmosphere Credit 1. Given these goals, more detailed definition of the building and its HVAC equipment is typically needed. The HAP detailed design interface is designed to help us perform these types of energy analysis.

1.3.6 Working with the HAP Main Program Window

Much of the work performed during entering data and generating reports is done using features of the main program window with key elements is shown below.

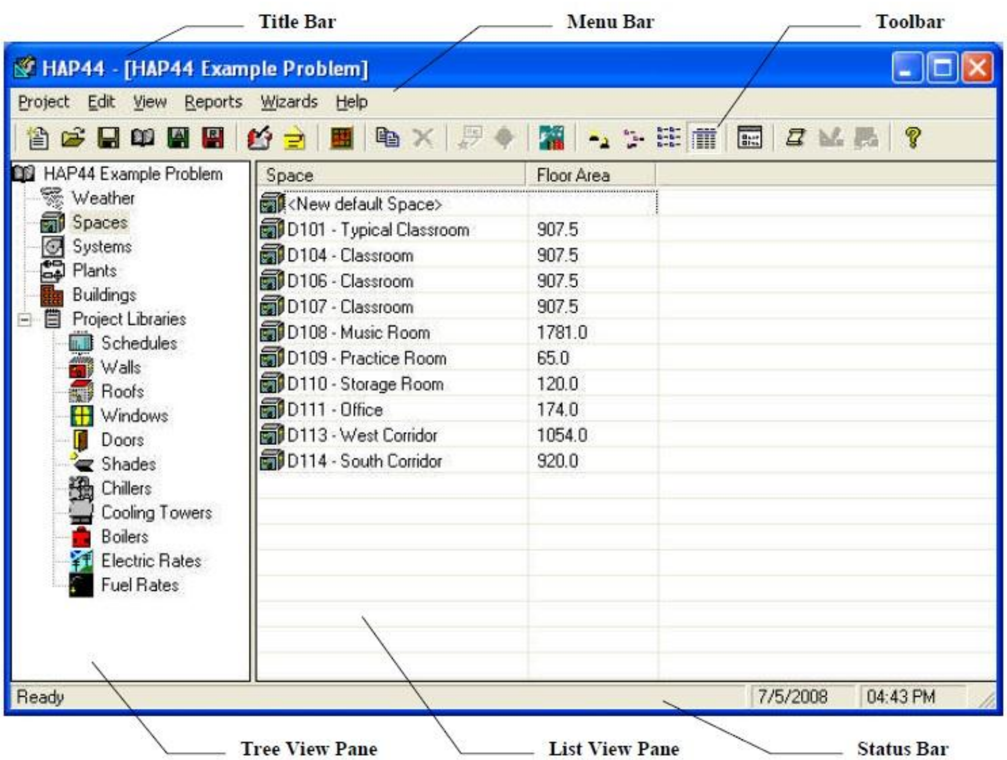


Figure 1.9: HAP Main Window

Key elements and features of the main program window are as follows:

(a) The Title Bar lists the program name and the name of the current project. If HAP System Design Load or the full HAP System Design mode is being run, the program name will be "HAP System Design Load". If the full HAP program with energy analysis features turned on is running, the program name will simply be "HAP". At the right-hand end of the title bar are command buttons for minimizing and maximizing the program window and for exiting from the program.

(b) The Menu Bar lies immediately below the title bar. The menu bar contains six pull-down menus used to perform common program tasks. To use menu options, we first click on the menu name to “pull down” its list of options. Then click on the name of the desired option. The six pull down menus are as follows:

(1) The Project Menu provides options for manipulating project data. This includes tasks such as creating, opening, saving, deleting, archiving and retrieving projects.

(2) The Edit Menu contains options used to work with individual data items such as spaces, systems, walls, roofs, etc.

(3) The View Menu offers options used to change the appearance of the main program window. This includes changing the format of data shown in the list view, turning on or off the toolbar and status bar, and setting user preferences such as units of measure. For HAP users, an option is also provided for switching between full HAP and HAP

System Design Load modes of program operation. This feature is used for projects which only require system design. In these cases, it is sometimes useful to simplify program operation by temporarily turning off the energy analysis features.

(4) The Reports Menu provides options for generating reports containing input data, design results and energy simulation results.

(5) The Wizards Menu contains options for running the Weather, Building, Equipment or Utility Rate Wizards separately, and for running a "Full Wizard Session" which integrates all four Wizards so we can rapidly generate data for a cost comparison study all at one time.

(6) The Help Menu contains options for technical assistance with the program. This includes options for displaying the on-line help system and the user's manual, contact information for Carrier software support, and links to web-based support materials and software training class information.

(c) The Toolbar lies immediately below the menu bar and contains a series of buttons used to perform common program tasks. Each button contains an icon which represents the task it performs. These tasks duplicate many of the options found on the pull-down menus.

Figure 1.10: HAP Toolbar

To determine the function of a toolbar button, we simply place the mouse cursor over a button. A "tooltip" will appear listing the function of that button. The toolbar buttons shown above appear by default when we first run the program. However, we can customize the toolbar by removing buttons that are not often used or arranging the buttons in a different order that is more efficient for us to use. To customize the toolbar, we have to double click on the toolbar. This will cause the "Customize Toolbar" dialog to appear. Options in this dialog are used to add and delete buttons, and to arrange the order of appearance of the buttons.

(d) The Tree View is the left-hand panel in the center of the main program window. It contains a tree image of the major categories of data used by HAP. The tree view acts as the "control panel" when working with program data:

(1) To display a list of items in one of the categories of data, click once on the category name. For example if we click on the Space category name, a list of spaces we have entered will appear in the list view panel on the right side of the main program window. Once a list of items appears, we can click on items in the list view to perform such tasks as creating new data, editing data and generating reports.

(2) To display a pop-up menu of options for the category, right-click on the category name. The "category pop-up menu" will appear. Options on this menu will perform tasks on all items in a given category. For example, if we right-click on the System category name, the System category pop-up menu will appear. If we select the Print Input Data option, input data for all systems in our project will be printed. Because options on the category pop-up menu operate on all items in a category, we should be careful using these options.

(3) To display a summary of project contents, we click once on the Project category name. A list of the major data categories (weather, spaces, systems, plants) will appear. If the "details" format is used for the list view, the quantity of items we have defined for each category will also be shown. For example, the summary shows the number of spaces and systems which have been defined.

(4) To display a summary of project library contents, we click once on the Project Libraries category name. A list of the library categories (schedules, walls, roofs, windows, doors, shades) will appear. If the "details" format is used for the list view, the quantity of items that we have defined in each category will be shown. For example, the summary shows the number of wall and roof assemblies we have defined.

(e) The List View is the right-hand panel in the center of the main program window. It contains a list of data items in alphabetical order for one of the categories of data in our project. For example, when the space category is selected, the list view shows a list of spaces we have entered. The list view acts as the second part of the "control panel" when working with program data. By selecting items in the list view we can:

(1) Create new items. Example: Creating a new schedule.

(2) Edit existing items. Example: Editing a wall assembly we previously defined.

(3) Duplicate an existing item. Example: Creating a new space using defaults from an existing space.

(4) Duplicate a building with all its spaces and HVAC equipment. This is often useful in LEED® EA Prerequisite 1 and EA Credit 1 analyses when making a copy of a Proposed Design building and all its spaces, systems, plants, chillers, towers and boilers to serve as the basis for assembling the Baseline Building.

(5) Delete existing items. Example: Deleting three systems we previously entered.

(6) Searching and replacing existing space data. Example: Change lighting W/sqft from 2.0 to 1.8 for 40 spaces all at one time.

(7) Rotating the orientation of existing spaces. Example: Rotate the orientation of 35 spaces by 45 degrees clockwise all at one time.

(8) Performing LEED (90.1 PRM) Rotations. This is used in a LEED® EA Prerequisite 1 and EA Credit 1 analyses to take a Baseline Building and make three copies of it, with spaces rotated 90 deg, 180 deg and 270 deg respectively.

(9) View or print input data. Example: Printing input data for four window assemblies that we previously entered.

(10) View or print design reports. Example: Viewing design reports for two air systems that we defined.

(11) View or print energy simulation reports. Example: Printing a building simulation report listing annual energy use and energy costs.

There are usually at least two or three ways of performing each task. For example, after selecting items in the list view, an option on the Edit or Report Menu can be selected, or a button on the Toolbar can be pressed, or an item pop-up menu can be displayed by right-clicking on the selected items.

(f) The Status Bar is the final component of the main program window and appears at the bottom of the window. The current date and time appear at the right-hand end of the status bar. Pertinent messages appear at the left-hand end of the status bar.

1.3.7 Working with HAP Input Forms

While much of our work with the program is done on the main program window, the actual entry of data is done using input forms. An input form appears when we choose to create a new item or edit an existing item. A separate input form is provided for each category of HAP data.

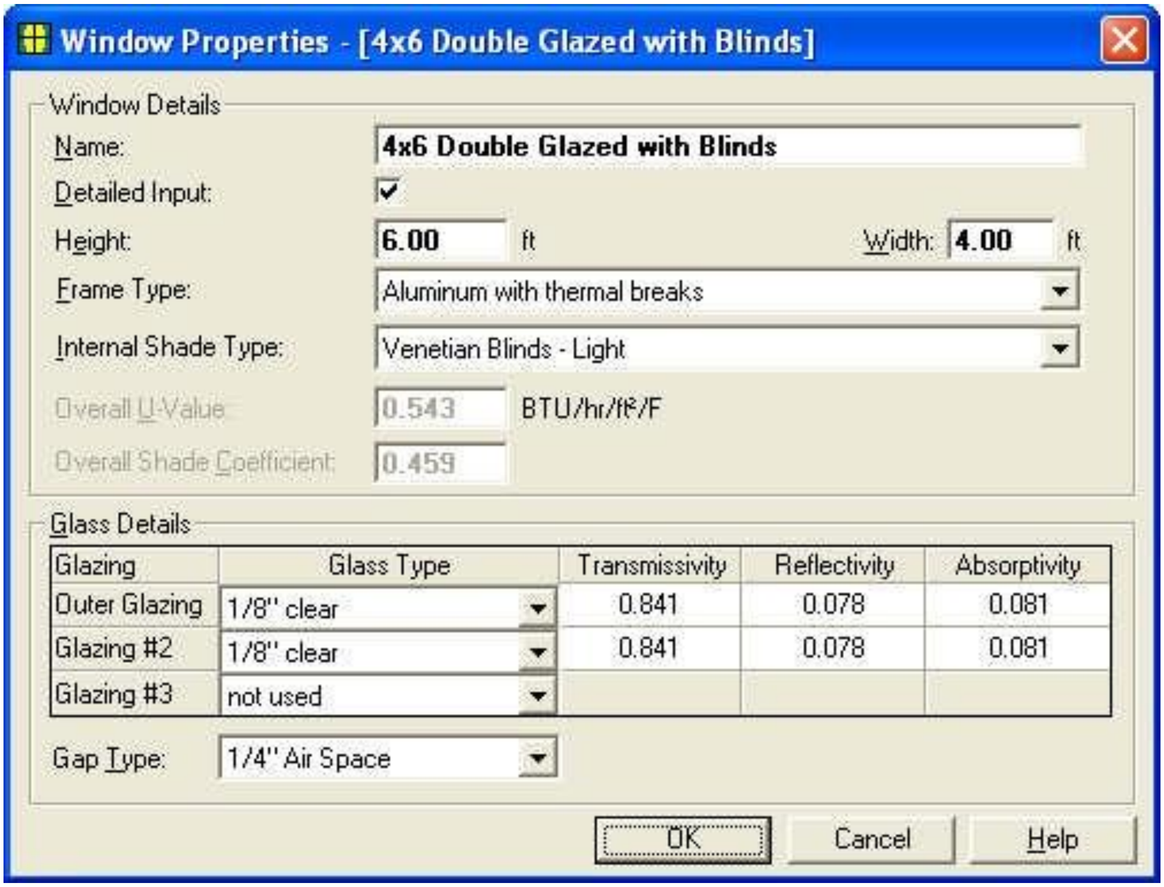


Figure 1.11: HAP - A Simple Input Form

(a) <u>Simple Input Forms</u>: Many input forms have a simple appearance as shown in Figure 1.11. These simple kinds of input forms consist of three components:

(1) The Title Bar is found at the top of the input form. It lists the type of data contained in the input form and the name of the current item being edited. In the example above, data for a window assembly named “4x6 Double Glazed with Blinds” is being edited. The title bar also contains a close button. If we press this button, the program will return to the main program window without saving any changes that we made on the form. Thus, the close button performs the same function as Cancel.

(2) The Data Area is the middle portion of the form. It contains all the data describing the current item. In the example above, the data area contains information describing a window assembly: its dimensions, framing properties, internal shades, glazings and thermal performance. While entering information in the data area, we can display explanations of each input item by pressing the F1 key. For example, if we press F1 while the cursor is on the “Frame Type” item in the figure above, the help topic for “Window Frame Type” will appear automatically. This feature is useful for learning about the program while we work.

(3) The Command Buttons are found in the lower right-hand portion of the form. All forms contain three buttons:

    (i) Press the OK button to return to the main program window after saving any changes made on the input form.

    (ii) Press the Cancel button to return to the main program window without saving any changes made on the input form. The Cancel button performs the same function as the close button in the title bar.

    (iii) Press the Help button to display an overview of the current input form. This overview describes how the input form is organized and how to use it. It also contains links to help topics for the individual input items on the form.

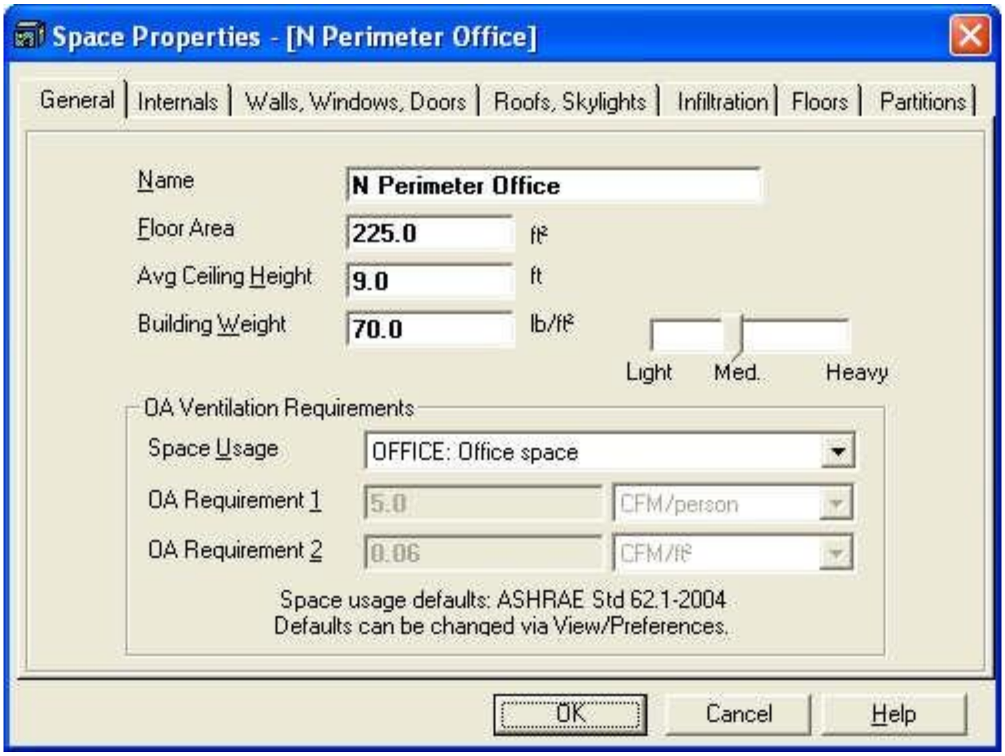


Figure 1.12: HAP - Tabbed Input Form

(b) For certain categories of HAP data, the input form has a more complex appearance as shown in Figure 1.12. This input form contains the same basic elements (title bar, data area, command buttons) as discussed earlier, but the data area contains multiple categories of information rather than a single set of information. Categories of data are represented as tabs in a notebook. In Figure 1.12, data for a 'space' is shown. Space data is divided into seven categories:

General data	Internal load data	Wall, Window, Door data
Roof, Skylight data	Infiltration data	Floor data
Partition data		

To switch between the different categories of data, we simply click on the tab title.

1.3.8 Working with Projects

While using HAP we will need to create and manage project data. This section discusses projects and features provided for managing project data.

(a) What is a Project? : All the data we enter and calculate in HAP is stored together within a "project". A Project is simply a container for our data. However, a project can hold data for other programs as well as HAP. For example, if we create a project for a building design job, it might contain load estimating and system design data from HAP, rooftop selection data from the Carrier Packaged RTU Builder program, and air terminal selection data from the Carrier Air Terminal Builder program. Keeping this data together in a single container is often more efficient than keeping the data in several separate locations.

(b) Using Projects: HAP provides a variety of features for working with project data. Common project related tasks are listed below.

(1) Create a new project.

(2) Edit data in an existing project.

(3) Save changes in a project.

(4) Save changes to a new project.

(5) Delete an existing project.

(6) Edit descriptive data for the project.

(7) Archive project data for safe keeping.

(8) Retrieve data that was earlier archived.

(9) Convert data from a previous version of HAP.

(10) Publish equipment sizing requirements so the data can be used in Carrier Electronic Catalog to make equipment selections.

(11) E-mail project data to the Carrier sales engineer for assistance with equipment selections.

(12) Export results to the Engineering Economic Analysis program for use in lifecycle cost studies.

(13) Import data from another project into the current project.

(14) Import data from Computer Aided Design (CAD) or Building Information Modeling (BIM) software.

(c) <u>How Project Data is Stored?</u> : When a new project is saved for the first time, we designate the folder which will hold the project files (either by accepting the default folder \E20-II\Projects\ProjectName or by specifying a folder ourselves). This folder is the permanent storage location of project data. When we open the project to work with its data, temporary copies of the project's data files are made. As we enter data, make changes and perform calculations, all this data is stored in the temporary copy of the data files. Only when we use the Save option on the Project Menu, the changes we made are copied to the permanent storage. Therefore, if we ever need to undo changes that were made to a project, we simply re-open the project without saving the changes that we

made. When we re-open the project, the changes stored in the temporary copy of the data files are discarded, and data from our last project/save is restored.

(d) Recommended Project Management Practices: Project data represents an important investment of our time and effort. And, as the saying goes, ‘time is money’. Therefore it is important to safeguard our investment in project data. It is recommend adopting the following practices when working with projects:

(1) Creating a separate project for each job we work on: It is usually more efficient to keep data for separate jobs in separate projects. It is also safer to store data in smaller, focused units. If we keep data for all jobs in a single project, and this project becomes damaged, our data loss will be greater than if we keep data for separate jobs in separate projects.

(2) Using a descriptive name for the project so we can quickly recognize what it contains, both now and when we need to refer to the project in the future. Because the selection list for projects is arranged alphabetically it is useful to use a consistent naming convention.

(3) Saving early and often. While entering data, changing data and generating reports, it is wise to save the project periodically. This practice is useful in the event that we make a mistake and need to undo changes.

(4) Archive the data periodically for safekeeping. These days data on hard disks is relatively safe. However, it is still possible for hard disk drives to become damaged, or for files on the hard disk to be damaged or erased. Therefore it is a good practice to periodically archive the project data.

1.3.9 Using the Help Resources in HAP

HAP provides extensive resources to help users learn about, understand and use the software. These resources are primarily available via the Help Menu on the menu bar of the main program window. The resources include:

(a) The On-Line Help System: The "Contents and Index" menu option launches the on-line help system. The help system contains introductory information, tutorials, examples, application information, and complete explanations of all program input screens and reports and calculation documentation. In addition, we can launch the on-line help system by pressing [F1] at any point during program operation or by pressing any of the Help buttons that appear on program input screens.

(b) The User's Manual: The "User's Manual" menu option launches your Adobe Acrobat Reader and displays the electronic copy of the program user's manual. This manual contains a subset of the information in the on-line help system which includes the introductory information, tutorials, example problems and application information.

(c) Telephone and E-mail Support: The "Contact Software Support" menu option displays telephone and e-mail contact information that we can use to contact Carrier software support for assistance with the program.

(d) Self-Directed Help on the Web: The "E20-II Support Web Site" menu option links us to the E20-II Application Support web page. This page provides self-service support materials such as frequently asked questions and "eHelps", which are short articles on common program topics of interest.

(e) Program Updates: The "Check for Program Updates" menu option links us to the E20-II Downloads web page where we can check to see if patch updates or major updates for the program have been released.

(f) Software Training Information: The "E20-II Software Training" menu option links us to the E20-II Software Training web page which contains class descriptions, a schedule of class dates and locations, and on-line class registration.

(g) Current Program Version Information: The "About HAP" menu option displays the current program version. This option is useful if we are unsure about having the latest version. The version displayed via this option can be compared with the versions shown in the E20-II Downloads web page.

1.4 REASONS FOR SELECTING ‘HAP 4.5’ OVER ‘EnergyPlus’

1.4.1 Unavailability of a Stable and Inexpensive Building modeling GUI

Many graphical user interfaces for EnergyPlus are available or under development. CYPE-Building Services, Demand Response Quick Assessment Tool, DesignBuilder, Easy EnergyPlus, EFEN, Hevacomp, HLCP, and MC4 Suite are now available. EPlusInterface is currently available in development (beta) versions. All these interfaces were powerful but required a purchase of licenses that were expensive. The pursuit to find an alternative GUI led us to Google Sketch Up. National Renewable Energy Laboratory of US Department of Energy provides a free plug-in for Google SketchUp; ‘OpenStudio’, that incorporates the functions of Energy Plus in Google SketchUp.

<u>About the ‘OpenStudio’ Plug-in</u>: OpenStudio Plug-in allows us to use the standard SketchUp tools to create and edit EnergyPlus zones and surfaces. We can explore our EnergyPlus input files by using all of the native SketchUp 3D capabilities to view the geometry from any vantage point, apply different rendering styles, and perform shadowing studies. The plug-in allows us to mix EnergyPlus simulation content with decorative content such as background images, landscaping, people, and architectural finish details—all within the same SketchUp model. The plug-in adds the building energy simulation capabilities of EnergyPlus to the SketchUp environment. We can launch an EnergyPlus simulation of the model that we are working on and view the results without leaving SketchUp. This plug-in made it easier to work with EnergyPlus.

However, expertise in using EnergyPlus at the text level is highly recommended for performing successful and accurate simulations. OpenStudio Plug-in does not yet handle all critical input objects. Some editing of the input file will usually be required outside of SketchUp. We can use a text editor, a third-party interface/tool, or other program (for example, the IDF Editor) to edit EnergyPlus input files.

The plug-in handles the modeling of only a certain number of zones and spaces in each zone with ease. However when an attempt to model the Building under consideration - ‘Building ‘C’ at Brunswick Community College’ was made, the task was extremely strenuous. Figure 1.13 illustrates the difficulty being encountered while trying to model the building.

Procedure adopted for modeling

(a) While modeling the building, there were 18 AHUs, each of which were considered as a separate zone due to the different temperatures at which they were maintained. These AHUs were to encompass 73 conditioned spaces.

(b) In the thermal building mode, all the boundary conditions were specified along with defining of each and every space.

(c) Every time a save was made, returning to the model after a while caused the explosion of the modeled building randomly into 3D space.

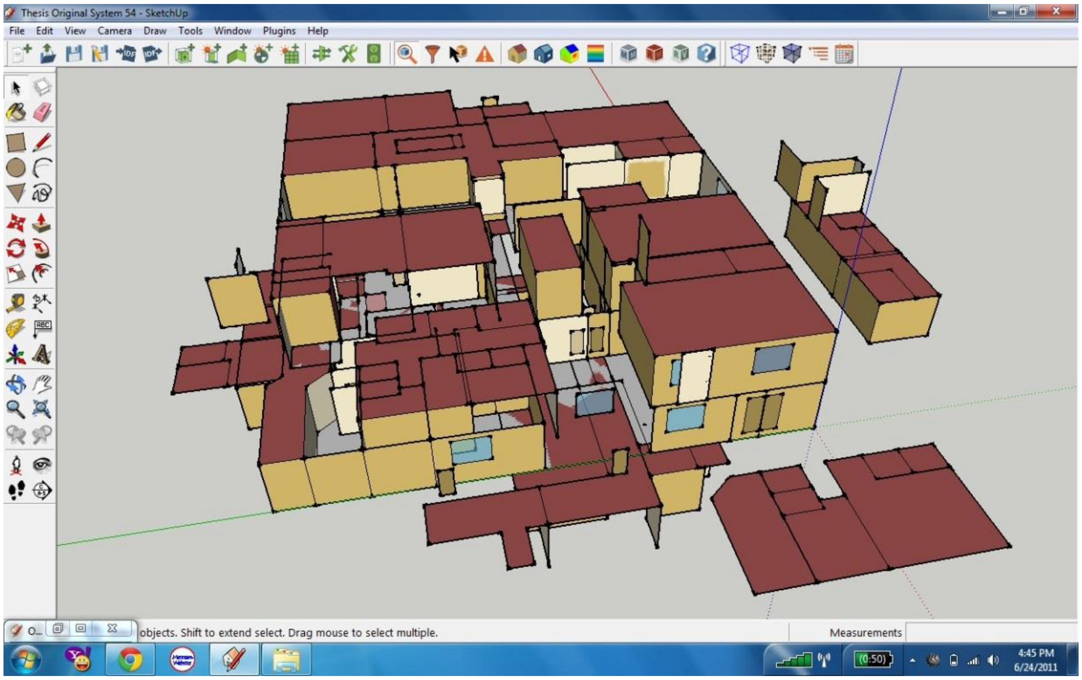


Figure 1.13: Distorted Open Studio Model in Google Sketch

(d) A check on a smaller example model was made to make sure that the error was not occurring for smaller models. Also proper results were obtained for smaller models which confirmed the proper functioning of the software for fewer zones and spaces.

(e) It should be noted that Energy Plus can still be run without a GUI. The only Herculean task in that case would be to define vertices of each and every wall, window, door or any other geometric figure that represents a part of the building in Global Coordinate System to create objects in EnergyPlus IDF file.

(f) It should also be noted that 'EnergyPlus' is very powerful software and when coupled with a proper GUI can be an easy and excellent energy modeling tool.

1.4.2 Conformity of Results generated by HAP 4.5 for a Case Study

HAP 4.5, which was readily available in lab machines at NCSU IAC, was used for the load analysis of TV Studios at UNC TV Bryan Center (discussed in detail in Chapter 2). On analysis of their current system, the capacity of AHUs obtained was the same as was supplied by UNC TV. This imparted us with confidence for using the software for Brunswick Community College's Building 'C' Analysis.

CHAPTER 2: CASE STUDY USING HAP 4.5

2.1 CASE STUDY DETAILS

HAP 4.5 was used to study the design and performance of the TV Studios at Bryan Center in UNC Chapel Hill, NC and to design more efficient HVAC retrofits. The spaces under consideration at Bryan Center were the Studios ‘A’ and ‘B’.

2.1.1 Issues with Space Operation and Overall Plan for the Case Study

Each of the studios was served by a separate constant volume air handling unit. Both the systems were deemed to be oversized because of their ability to cool down the spaces in a very little time, once they were left unoccupied. The maintenance staff also informed us of the schedule of operation of the large interior ‘entry doors’ to the studios. Apparently, they were left open during the non-operating periods. On observation of the studios during non-operating periods, it was determined that Studio A was operating under a relatively higher pressure as compared to the internal space and Studio B was operating at a relatively lower pressure as compared to the internal space. This was deduced from tracking of the direction of flow of air when the doors were left open. The primitive assessment of the flow rate showed it to be pretty high for Studio A and lower for Studio B. It was decided to model the studios with their actual conditions of operation to have a rough overview of their performance. It was also decided to compare those models to the capacity and cost of operation of auto-computer generated models which were running for studio operating periods. It was also decided to put in rooftop AHUs which would operate during the no-

occupancy period of the studios. It was decided to see whether an improvement of performance (in terms of cost of operation) would result as a consequence of this act and calculate the payback period for the purchase of rooftop AHUs.

2.1.2 Construction Details

The construction and architectural plans for the spaces obtained from the facility maintenance staff of the studios provided the following information.

Wall Construction
Outside
4" Brick
1/2" Sheathing
6" MET Studs at 16" O.C W/6" Blanket Insulation
5/8" Gypsum Board
4" Solid C.M.U
Inside

Floor Construction
Inside
5" Concrete Slab
Vapor Barrier
4" Crushed Stone
Ground

Figure 2.1: Constructions of Studios at Bryan Center

(a) It was given that the thermal resistance values of wall and roof were $23 \frac{\text{hr-ft}^2\text{-}^{\text{O}}\text{F}}{\text{Btu}}$ and $22.5 \frac{\text{hr-ft}^2\text{-}^{\text{O}}\text{F}}{\text{Btu}}$ respectively.

(b) From the plans, it was observed that the average height of the spaces was 26 ft. 8 inches.

(c) There were no windows on any of the studios. However, there was an external door on studio B whose area was about 60.5 ft^2.

(d) An inquiry with the personnel at the facility indicated the roof to be ‘light’ colored.

(e) A visual inspection confirmed the color of the exterior of the studios to be ‘Grey’.

(f) We also observed that a part of the south east wall of Studio A was covered by the adjacent rooms of the building contributing to reduced solar load on this wall as compared to its complete exposure.

2.1.3 Load Details

Table 2.1: Load Details for Studios at Bryan Center

STUDIO →	**A**		**B**	
OCCUPANCY ↓	**LIGHTING LOAD (kW)**	**PEOPLE LOAD (NO. OF PEOPLE)**	**LIGHTING LOAD (kW)**	**PEOPLE LOAD (NO. OF PEOPLE)**
OCCUPIED	70	100	40	40
UNOCCUPIED	0	4	0	4

2.1.4 AHU Details

(a) The supply air and return air fans for Studio A were rated at 20 BHP and 15 BHP respectively.

(b) The supply air and return air fans for Studio B were rated at 15 BHP and 10 BHP respectively.

(c) The AHUs for both the studios were draw through units.

(d) The air was returned to the AHU through Ducted Return.

(e) Supply air CFM for Studio A = 25,000 CFM and that for Studio B = 20,000 CFM.

2.2 ASSUMPTIONS

2.2.1 Assumptions related to Weather and Run Period

(a) Weather: The weather file for Raleigh/Durham was selected as a design Parameter.

(b) The simulation was requested for a period of 12 months in 2011.

(c) It was assumed the studios were not operating on weekends and Federal Holidays [(1)].

Friday, December 31, 2010	New Year's Day
Monday, January 17	Birthday of Martin Luther King, Jr.
Monday, February 21	Washington's Birthday
Monday, May 30	Memorial Day
Monday, July 4	Independence Day
Monday, September 5	Labor Day
Monday, October 10	Columbus Day
Friday, November 11	Veterans Day
Thursday, November 24	Thanksgiving Day
Monday, December 26	Christmas Day

Figure 2.2: List of Federal Holidays for 2011

(d) The daylight savings were activated for the reporting of times and the beginning and ending dates of DST were given as March 13 and November 6 respectively.

2.2.2 Assumptions related to Space Data

(a) The building was assumed to be of medium construction. Selecting this option automatically gave a building weight of $70\frac{\text{lb}}{\text{ft}^2}$.

(b) For 'Minimum Outside Air Ventilation Requirements', the space usage was assumed as 'MISCELLANEOUS: Photo Studio' – ($5\frac{\text{CFM}}{\text{Person}}$; $0.12\frac{\text{CFM}}{\text{ft}^2}$) [(2)].

(c) Since no explicit information regarding the ‘Overhead Lighting’, ‘Electric Equipment’ and ‘Miscellaneous Sensible - Latent Loads’ was provided, they were assumed to be non-existent.

(d) The following Lighting and Occupancy Schedules were assumed:

Table 2.2: Lighting and Occupancy Schedules for Studios A and B

Studio A			
Lighting		People	
Time	% of Full Load	Time	% of Maximum Occupants
0:00	0	0:00	4
1:00	0	1:00	4
2:00	0	2:00	4
3:00	0	3:00	4
4:00	0	4:00	4
5:00	0	5:00	4
6:00	50	6:00	50
7:00	100	7:00	100
8:00	100	8:00	100
9:00	100	9:00	100
10:00	100	10:00	100
11:00	100	11:00	100
12:00	100	12:00	100
13:00	100	13:00	100
14:00	100	14:00	100
15:00	100	15:00	100
16:00	100	16:00	100
17:00	100	17:00	100
18:00	100	18:00	100
19:00	100	19:00	100
20:00	50	20:00	50
21:00	0	21:00	4
22:00	0	22:00	4
23:00	0	23:00	4

Studio B			
Lighting		People	
Time	% of Full Load	Time	% of Maximum Occupants
0:00	0	0:00	10
1:00	0	1:00	10
2:00	0	2:00	10
3:00	0	3:00	10
4:00	0	4:00	10
5:00	0	5:00	10
6:00	50	6:00	50
7:00	100	7:00	100
8:00	100	8:00	100
9:00	100	9:00	100
10:00	100	10:00	100
11:00	100	11:00	100
12:00	100	12:00	100
13:00	100	13:00	100
14:00	100	14:00	100
15:00	100	15:00	100
16:00	100	16:00	100
17:00	100	17:00	100
18:00	100	18:00	100
19:00	100	19:00	100
20:00	50	20:00	50
21:00	0	21:00	10
22:00	0	22:00	10
23:00	0	23:00	10

(e) The ‘Activity Level’ of people in the studios was assumed to be ‘Medium Work’.

(f) Though the total thermal resistance value for the roof had been given, an input in HAP could only be specified by giving layers of the roof. So the following roof construction was assumed. This combination of layers was reasonably close to the one observed from construction charts and gave us the ‘R’ value as desired.

Layers: Inside to Outside	Thickness	Density	Specific Ht.	R-Value	Weight
	in	lb/ft³	BTU/lb/F	hr-ft²-F/BTU	lb/ft²
Inside surface resistance	0.000	0.0	0.00	0.68500	0.0
R-22 batt insulation	6.750	0.5	0.20	21.15000	0.3
Built-up roofing	0.375	70.0	0.35	0.33245	2.2
Outside surface resistance	0.000	0.0	0.00	0.33300	0.0
Totals	7.125			22.50	2.5

Figure 2.3: Roof Construction for Studios

(g) For studio A, as described in case study details, there was a positive pressure which led to the escape of air through the door when left open. This air was estimated to be around 5000 CFM and was considered as a direct exhaust to the system.

Estimation: Height of the door (H_A) = 15 ft; Width of the door (W_A) = 10 ft

The velocity of air escaping Studio A (V_A) = 33 ft/min

$\therefore$ Volumetric flow rate of air from Studio A = $H_A \times W_A \times V_A$

$= 15 \text{ ft} \times 10 \text{ ft} \times 33 \text{ ft/min} \simeq 5000 \text{ CFM}$

(h) For studio B there was a negative pressure which caused air to get into the space. However the amount of air entering was relatively very small as compared to the amount of air escaping from studio A. It was estimated to be around 1500 CFM. The infiltration was assumed to occur at all hours for the purpose of getting a design value.

Estimation: Height of the door (H_B) = 15 ft; Width of the door (W_B) = 10 ft

The velocity of air entering Studio B (V_B) = 10 ft/min

$\therefore$ Volumetric flow rate of air into Studio B = $H_B \times W_B \times V_B$

$= 15 \text{ ft} \times 10 \text{ ft} \times 10 \text{ ft/min} = 1500 \text{ CFM}$

(i) An Edge Insulation R-value of 10 $\frac{\text{hr-ft}^2\text{-}^{\circ}\text{F}}{\text{Btu}}$ was assumed.

2.2.3 Assumptions related to Air Systems

(a) The Ventilation Sizing Method assumed was ‘Sum of space OA airflows’.

(b) The unoccupied space damper position was assumed to be in ‘Open’.

(c) An outdoor Air CO_2 Level of 400 ppm was assumed. (Which was a default value)

(d) The systems were assumed to not have Economizer, Vent. Reclaim, Precool Coil, Preheat Coil, Humidification and Dehumidification equipment.

(e) A supply temperature of 58^{O}F was assumed.

(f) A coil bypass factor of 0.1 was assumed. (Which was a default value)

(g) The capacity control for cooling was set to ‘Cycled or Staged Capacity, Fan On’.

(h) A design heating temperature of 95^{O}F was assumed.

(i) The heating source was assumed to be hot water.

(j) The capacity control for cooling was also set to ‘Cycled or Staged Capacity, Fan On’.

(k) The supply and return fans are assumed to be ‘Forward Curved’ type.

(l) The Duct Heat Gain and Duct Leakage were assumed to be 0%.

(m) The Cooling T-stat Setpoints were assumed to be:

Occupied: 75^{O}F   Unoccupied: 85^{O}F

(n) The Heating T-stat Setpoints were assumed to be:

Occupied: 70^{O}F   Unoccupied: 60^{O}F

(o) The T-stat Throttling Range was assumed to be 1.5^{O}F. (Which was a default value)

(p) The diversity factor was assumed to be 100%. (Which was a default value)

(q) There was no ‘Direct Exhaust’ for Studio B. There was a direct exhaust from Studio A as discussed in ‘Assumptions Related to Space Data: (g)’. Since the cause of exhaust of this air was opening the door, there was no Direct Exhaust Fan. Thus the power of Direct Exhaust Fan was left at 0 kW.

(r) The supply terminals were assumed to be of ‘Diffuser’ type.

(s) The reheat was assumed to be absent for either of the studios.

(t) The Chilled Water ΔT was assumed to be $10^{O}F$ and the Hot Water ΔT was assumed to be $20^{O}F$.

(u) No Safety factor of was used for any of Cooling Sensible, Cooling Latent and Heating loads because actual situation was to be modeled.

(v) A standard ventilation rate of 8 ACH was assumed as per the CIBSE Guide B2 [(3).]

Table 2.3: Ventilation CFM for Studios at Bryan Center

Studio ↓	Floor Area (ft^2)	Height (ft)	Ventilation CFM $= \text{ACH}\ (\frac{1}{hr}) \times \text{Floor Area}\ (ft^2) \times \text{Height (ft)} \times \frac{1\ hr}{60\ min}$
A	3917.6	27.6	13800
B	2748.5	27.6	9700

<u>Note</u>: It should be noted that the lower hundredth limit was considered as the CFM value.

2.3 RESULTS

By utilizing the case study details and assumptions as stated in the sections 2.1 and 2.2, a HAP 4.5 simulation was run. The resulting reports have been shown in Appendix A. It can be observed from these reports that the design cooling capacities of the air handling units serving the studios A and B are 58.4 tons and 46.7 tons respectively. The data obtained from the maintenance personnel at UNC-TV Bryan Center indicated that the actual cooling capacities of the air handling units serving the studios A and B were indeed 58.4 tons and 46.7 tons respectively. This conformity of results fortified our confidence in HAP 4.5 and encouraged its utilization for the analysis of HVAC system of Building ‘C’ at Brunswick Community College.

CHAPTER 3: DETAILED ANALYSIS OF BUILDING ‘C’

The most effective methodology of analyzing Building ‘C’ in detail would be to start from the initial problem and proceed in a chronological fashion to understand the amendments made to the system and their impact on its performance. The project involved multiple visits to the building, monitoring and analysis of data over time and suggesting recommendations that would be beneficial to the building from both energy and economic point of views.

3.1 THE FIRST VISIT (04/23/2010)

3.1.1 Observations

This visit conducted by Dr. Herbert Eckerlin gave an overview of system configuration, its performance and the problems being encountered by the maintenance personnel and the occupants of the building. The visit brought the following issues to light.

<u>Humidity Issue</u>: The Building had a serious humidity problem which still exists today. The problem was non-uniform throughout the building. The computer room and one of the offices in the first floor appeared to be the most troublesome with the computer room encountering the more serious humidity problem. Dehumidifiers were required to be run continuously and had to be emptied every day. The relative humidity in the conditioned air was consistently high (in the 60-70% range). The high humidity, apart from causing discomfort, also affected the operation of copiers and printers.

Figure 3.1: Dehumidifier being used in Copier Room

<u>AHU Operation</u>: Typical temperature rise across the AHU Cold Water coils was 15 - 20^{O}F as compared to the recommended 10^{O}F rise.

<u>Boiler Operation</u>: The Boiler was initially operating during the summer. With the arrangement of hot water coils preceding cooling coils in the AHUs, the heat added due to this operation of boiler only increased the cooling load on the cooling coils.

<u>Chiller Operation</u>: One of the chiller circuits was not operating because of a faulty expansion valve which raised apprehensions about the adequacy of cooling capacity being supplied to the building. The readout at the chiller indicated that the entering water temperature was higher than the leaving water temperature (by 0.5 to 1.5 ^{O}F). The temperatures were in the

44 – 46^{O}F range. The temperature of the water returning to the chiller (on the monitor in the Maintenance Building) was ~ 83^{O}F. These observations were contradictory to each other.

Miscellaneous Observations:

(a) The biology room windows were generally left opened during the day. This might have been a factor that contributed to the humidity issues.

(b) The blinds of certain parts of the building which were subjected to high amount of direct solar gain were left open. This could have contributed to the increase of cooling load of the building. e.g. Room 229

(c) "Iron fouling" was indicated to be present. It is a common problem in systems where the water has not been treated. This fouling causes iron particles to break off and be distributed throughout the system. This process causes plugging in the CHW system that dramatically reduces CHW flow and distribution.

3.1.2 Recommendations

(a) It was recommended to turn the boiler off during the summer to eradicate the wasteful use of energy which in turn increased the cooling load on the cooling coils.

(b) It was also recommended that the placement and operation of the temperature sensors be checked by Maintenance or Service Provider.

(c) A heat balance procedure across the chilled water coils was recommended to yield a design flow rate of the chilled water. A comparison of this value with the actual flow rate value was suggested.

(d) Data regarding the temperature and humidity of various rooms was deemed necessary to understand the situation.

(e) It was also recommended that the quality of water be checked by an authorized testing agency. A complete flush out of the system and replacing the water with chemically treated water was suggested.

3.2 THE JULY 2010 VISITS

During these visits, Dr. Herbert Eckerlin and Mr. Doug Gunnel returned to the campus a number of times to gather additional data on the operation of the HVAC system. Of particular interest was the temperature and relative humidity data on July 29, 2010 for various rooms (Appendix B1). July 29 was a particularly hot and humid day (e.g., 89.7°F Dry Bulb (db), 82.4°F Wet Bulb (wb), and 73.8% Relative Humidity (RH)) that placed a large cooling load on the HVAC system.

The attached July 29, 2010 data shows that the HVAC system was not able to provide acceptable humidity levels on that day. Further investigations with the maintenance personnel disclosed that the chilled water control valves were only partially open (i.e., about 35 to 50%). When the power to the valves was removed, the valves went wide open.

3.3 8TH SEPTEMBER 2010 VISIT

3.3.1 Observations

The AHUs appeared to operate satisfactorily on the 9-8-10 with the CHW control valves wide open. There was concern that the HVAC system would not be adequate under warmer, more humid conditions (as had been experienced in the past). This day was not a design day and the db and wb temperatures of the air leaving the AHU were low. In fact, many of the rooms were noticeably cold. The RH was in an acceptable range. The ambient conditions were less severe than in July and the HVAC system was able to satisfy room comfort requirements. However, all the chilled water valves were fully (100%) open, rather than only 30 -50% open. The chilled water valves did not appear to be under any sort of control. The overall uncertainty on the mode of control led to situation which necessitated the consideration of evaluation of the complete control system as an imperative task. Also, the controls for the CHW valve on AHU #3 appeared to be reversed.

Figure 3.2: Chilled Water Control Valve 100% Open

The back of the building had a large solar load. The Principal's Office was an uncomfortable $82^{O}F$.

3.3.2 Recommendations and Actions

(a) It was imperative that the building AHU design drawings be provided to verify the negative pressure in the building.

(b) It was suggested to the principal to close the blinds. In 10 minutes, her disposition improved dramatically!

(c) It was suspected that the HVAC system did not have the capacity to take care of the sensible heat load and the moisture in the air under heavy load.

(d) There was an apprehension of the building being under negative pressure which had to be verified. In such a case, the outdoor air would be drawn into the building in an uncontrolled manner. To properly control humidity, a building must be under positive pressure. For Building ‘C’, this would require additional HVAC equipment (i.e., a dedicated de-coupled ventilation unit).

(e) HOBOs were placed in various locations of the building to monitor supply air and room condition temperatures and relative humidities of the spaces for a period of one month. One HOBO was placed near the chiller outside the building to monitor the ambient conditions. Another HOBO was placed to measure the chilled water return temperature.

3.4 VISIT ON 10/07/10

3.4.1 Observations

Negative Pressurization: Originally, a relative negative pressure was present in the building as compared to the ambient conditions. The HVAC plans showed a 6,800 CFM of exhaust versus only 4,800 CFM of fresh air supply. This imbalance created a negative pressure in the building. Opening the entrance doors of the building indicated the direction of flow of air which confirmed the negative pressure. The exhaust requirement of Cosmetology Lab contributed significantly to the negative pressure in Building "C," which in turn made humidity control difficult.

Rearrangement of Rooms: As the College had grown and changed over the years, the rooms in Building "C" had been reconfigured. Consequently, there could have been a mismatch between the AHUs and the rooms that they presently served. An example of this problem was Classroom 135 (adjacent to Cosmetology). On entering this room at 2:30 PM, after classes had been let out, the room was very stuffy and reeking of cosmetology odors.

Sand in Chilled Water Lines: The plant personnel indicated that the water in the region was very sandy. The chilled water valves were very small and a little sand could easily get stuck in a valve and cause it to malfunction. This becomes a particular problem during system startup when the settled out sand begins to reenter the flow stream.

Control Dampers in Return Air Duct: The HVAC contractor indicated that a damper had been installed in the return air duct upstream from the fresh air union to reduce the return air flow and thus increase fresh air into the system. An examination of this claim indicated otherwise.

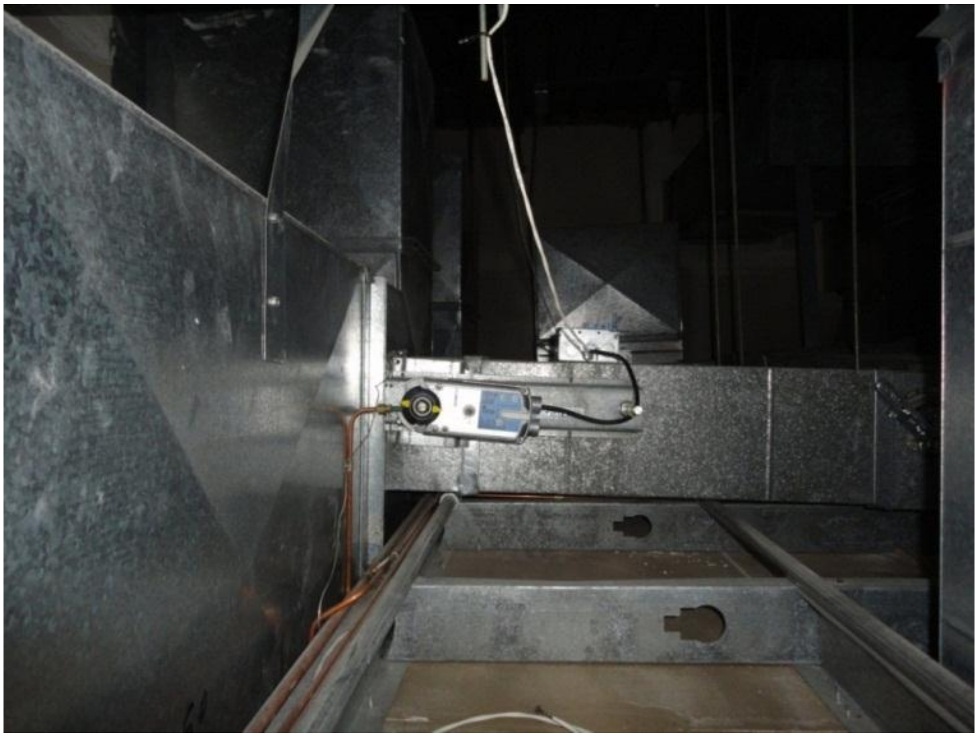


Figure 3.3: Absence of Damper on Return Air Duct

Makeup air duct dampers: The operation, purpose and use of automatic control dampers installed in the makeup air ducts were unclear. Since the makeup air ducts were small, it was questionable if the valves were ever utilized.

3.4.2 Recommendations and Actions

(a) The HOBOs placed in various rooms were collected and were scheduled for readout and analysis. The HOBO placed under the chiller malfunctioned due to the adverse weather conditions and did not give any values. Therefore the data had to be obtained from online sources [(4)]. The data obtained from the HOBOs and online sources was plotted on a monthly and weekly basis, the plots of which have been shown in Appendices B2 and B3 respectively. These plots provided valuable information on the variations among the ambient, supply and room temperature and relative humidities. It was observed from these plots that the relative humidity in different spaces was consistently high in uncomfortable range.

(b) The negative pressurization of the building draws air into the building which contributes to the humidity problem. To properly control humidity, the building will have to be pressurized. If more fresh air is drawn in to pressurize the building, the load on the chiller will be increased. It was recommended that the capacity of the chiller be checked under these new conditions.

(c) It was recommended that the CHW controls be appropriated to responsible personnel. It was also recommended that the entire control system be serviced, with the applicable components calibrated/replaced as required, to ensure that the system functions as designed.

(d) If the HVAC system was to be upgraded, it was indicated that consideration should be given to separating HVAC for Cosmetology from the rest of the building. Some consideration should also be given to the original HVAC plan to make appropriate modifications to fit the present building arrangement and use.

(e) Since the evidence of presence of sand in the water was not obvious, it was recommended that the system be opened and checked for this problem.

(f) To understand and document the rearrangement of rooms, it was suggested to obtain the original plans and compare them with the present room arrangement for identifying areas of mismatch.

3.5 MEETING ON 10/26/2010

This meeting shed light on some new issues regarding the performance of building ‘C’. A summary of the new issues and corresponding recommendations are as follows.

Chilled Water Temperature Rise across Cooling Coil

It was generally agreed that the unusually high temperature rise across the chilled water coils could be caused by a chilled water circulation problem which could in turn be caused by:

(a) A malfunctioning circulation pump. Corrosion could be a suspected problem.

(b) Rust and other debris that is clogging the chilled water circulation system, or

(c) A combination of these two factors.

Recommendation:

Step 1: To engage the services of a water treatment specialist to evaluate the condition of the chilled water circulation system in Building ‘C’. This was to involve flushing the entire system, opening up the system at the inlet to the chilled water coil at each air handling unit, and removing all the rust and debris.

Step 2: Since the circulation had not been adequately treated in the past, there was the distinct possibility that rust would continue to break off in the internal piping and create future circulation problems. To guard against this, it was recommended that "Y-strainers"

with hose end drain valves be installed at the inlet to each chilled water coil and other critical locations in the system.

Step 3: The final step of recommendation was to install a new chilled water pump with a variable frequency drive, along with a totalizing water flow-meter.

Water Quality

The Brunswick Community College personnel indicated that the water in the region had high iron content and was very corrosive. The experience in Building 'A' had confirmed the corrosion problem.

Recommendation: It was suggested to check with the water treatment specialist for recommendations on how the chilled water circulation system should best be treated.

Iterative Process

It was generally agreed that solving the Building 'C' humidity problem would be an iterative process. As indicated above, the first step was to clean up the chilled water circulation system and determine the impact on HVAC system performance. After the above recommendations have been implemented, the performance of the HVAC will have to be re-evaluated. The results of these tests were to determine the next step

Clean Up Air Distribution System

It was noted that the interior of the supply and return ducts, as well as the supply diffusers and return grills had significant dust build-up.

Recommendation: It was recommended to engage the services of a duct cleaning specialist to inspect the interior of the supply and return ducts. Cleaning or replacing the components as required would ameliorate the system.

Future Challenges

The exhaust requirement of Cosmetology contributed significantly to the negative pressure in Building ‘C’, which in turn made humidity control difficult. To properly control humidity in the future, the building would have to be pressurized and dehumidification control implemented. As a harbinger thought it was suggested that one approach would be to convert the air handling systems to variable air volume (VAV) with coil discharge air temperature control which would require variable speed drives on the AHU motors, control modification, plus reheat coils installed in some of the ducts.

Activity Preceding the Meeting

In the period after the day of meeting, the following activities were carried out.

(a) Extraction of various details of the building from the architectural, civil, construction, electrical and mechanical charts provided by the Director of Brunswick Community College’s Physical Plant, Ms. Donna Baxter.

(b) Attempts were made to model the building using ‘Energy Plus’. But ‘HAP 4.5’ was used instead of ‘Energy Plus’ because of the reasons specified in section 1.4.

(c) Some of the inputs were provided by the tests conducted on the building’s HVAC system by Palmetto Air & Water Balance. This data is shown in Appendix C6.

3.6 CORRESPONDENCE WITH PALMETTO AIR & WATER BALANCE

Palmetto Air & Water Balance conducted some studies on the subject building to correct the negative pressure under which Building ‘C' had been operating. Specifically, they opened the dampers in the fresh air ducts feeding the air handling units. In the course of their work, they were able to get the building under a positive pressure.

From our correspondence with ‘Palmetto Air and Water Balance’, it was found that there was an imbalance in the pressure drop through the CHW coils versus the bypass line. There was a control valve on the CHW line and no control valve on the bypass line. This caused a greater flow of chilled water in the bypass line than the chilled water lines. This could have had a significant impact on the ability of the AHUs to remove moisture from the air.

It was indicated by the personnel at Brunswick Community College that in the period after the meeting, a new Variable Frequency Drive (VFD) had been installed on the CHW circulation pump.

After the Palmetto balancing, the personnel expressed an acceptable system performance only to contact back in a few weeks to inform about the return of the humidity problem, this time with greater degree of severity. Most of the water seemed to have come from the sweating grills.

‘Palmetto Air & Water Balance’, sent a serviceman to investigate the situation and he confirmed a relative negative pressurization of the building. He determined that the cause of this change in pressure were two large exhaust fans that were drawing air out of the building. One fan served the mechanical equipment room (Room No. 140) and the other served to cool the electrical room (Room No. 141). It was found that apparently, the original air balancing was done with the exhaust fans turned off.

3.7 VISIT ON 09/02/2011

3.7.1 Observations

(a) On this visit we were informed that the severe humidity problem that had been recently expressed was due to the presence of holes in the ceiling in Rooms 140 and 141, which had been drawing air from the conditioned space and was in turn being exhausted by the exhaust fans in these rooms. The covered holes in these rooms have been shown in Fig. 3.4.

Figure 3.4: Covered holes in Rooms 140 and 141

The personnel at Brunswick Community College indicated that the building conditions ameliorated, once these holes were closed with sheetrock.

(b) The window in the mechanical room (Room 140) had been left partially open to satisfy the air volume needs of the mechanical room exhaust fan. The electrical room (Room No. 141) did not have any access to outside air. This meant that the exhaust fan in it drew its air volume needs from the interior of the building.

(c) During this visit, the increase in chilled water temperature across the chilled water coils in 14 of the 18 air handling units was measured, the details of which are shown below.

Table 3.1: Chilled Water Temperature Rise across the Cooling Coils

AHU	T_{In}	T_{Out}
1	46	68
2	45	70
3	44	76
4	47	23
5	47	60
6	69	76
7	45	88
8	45	61
9	45	62
10	45	67
11	45	61
12	47	70
13	45	56
14	45	61

This data suggested the following:

(1) The chilled water temperature of approximately 45°F indicated that the chiller was working properly.

(2) The increase in chilled water temperature across the CHW coils was much higher than usual. A temperature rise of 10°F is normal (i.e., 45°F → 55°F).

(3) Temperature increases of 15°F to 30°F suggested chilled water flow problems through the CHW coil. This could have been caused by the chilled water bypassing the coil (in a 3-way valve arrangement), or possibly restrictions on the water side of the coil. Since the water side was recently cleaned, excessive bypass flow was indicated.

(d) Upon entering Cosmetology Lab, we immediately noticed the warm humid air in the room. The HVAC system did not appear to satisfy the temperature or humidity problems in the building. The maintenance personnel indicated that the two dehumidifiers in Cosmetology Lab had to be emptied three times daily between 7:00 am and 3:00 pm. This reflected on the seriousness of the moisture problem.

(e) The velocity of air coming out of the vent at the exhaust fans was measured and was found to be in the range of 1500 to 2000 $\frac{\text{ft}}{\text{min}}$. The size of the vent near the exhaust fan from the mechanical room (Room No. 140) was found to be around 28”×43”. Since the

holes in the ceiling of this room were closed, these figures gave an exhaust requirement of around 12542 to 16722 CFM.

Figure 3.5: Exhaust Fan Air Vents

3.7.2 Recommendations

(a) To eliminate the withdrawal of conditioned air by the electrical room exhaust fan, it was recommended that an opening be cut in the rear of the wall that separated the two equipment rooms. This would allow air from the open window in the mechanical room to also pass through the electrical room and thus satisfy the needs of the electrical room exhaust fan.

(b) It was recommended to check with the valve manufacturer to determine the possibility of modification of the 3-way valve to comply with a 2-way valve operation. If this was not possible, the 3-way valves would have to be replaced with 2-way valves.

(c) Upon the successful completion of above step, it was recommended that Palmetto be contracted to use the circuit setters to set the chilled water flow through the coil (in each AHU) to match the flow specified on the drawings.

(d) After water balancing would be achieved, it was recommended to service and tune-up the HVAC Energy Management System. This would include an evaluation of all sensors/thermostats that ultimately control the system.

CHAPTER 4: USING HAP 4.5 TO MODEL BUILDING ‘C’

4.1 DATA OBTAINED FROM CHARTS

(a) The data relating the type of construction used for walls, floor, roof and interior ceiling has been shown in Fig. 1.2.

(b) Each air handling unit was considered to serve a zone which encompassed certain spaces, the details of which were extracted from the ductwork charts. For convenience each AHU was designated with a color (Fig.4.1). White color designated spaces that were assumed as unconditioned. The mechanical charts provided the design supply air and outside air CFMs of the originally intended system which are shown in Appendix C2. These charts also indicated the power rating of the supply air fans.

Figure 4.1: Designated colors for AHUs

(c) The architectural charts indicated the various dimensions of the building which are shown in Appendix C1. These charts showed the average height of each floor to be approximately 13 feet.

(d) The electrical charts provided the electrical outlet ratings and schedules which in turn provided the maximum wattage use for each space as is shown in Appendix C3.

(e) The lighting charts gave data regarding the lighting fixture schedule and the fixtures in each room which gave the maximum lighting wattage in each space as shown in Appendix C4 and C5 respectively.

4.2 ASSUMPTIONS OF DATA INPUTS TO HAP 4.5

4.2.1 Assumptions related to 'Weather and Run Period'

(a) Weather: The weather file for Wilmington, North Carolina was selected as a design Parameter.

(b) The simulation was requested for a period of 12 months in 2011.

(c) It was assumed the building was not operating on weekends and Federal Holidays (1). (Fig 2.2).

(d) The daylight savings were activated for the reporting of times and the beginning and ending dates of DST were given as March 13 and November 6 respectively.

4.2.2 Assumptions related to 'Space Data'

(a) The building was assumed to be of medium construction. Selecting this option automatically gave a building weight of $70\,\frac{\text{lb}}{\text{ft}^2}$.

(b) Since no explicit information regarding Task Lighting and Miscellaneous Sensible – Latent loads was given, they were assumed to be non-existent.

(c) Assumptions regarding maximum occupancy and load/occupancy schedules of the spaces were made based on the nature of usage of the spaces and their floor area. These assumptions were also based on some general inquiries made at the site. The data regarding these assumptions have been shown in Appendices C7, C8 and C9. As can be seen from Appendix C8, two profiles were defined for the schedules. Profile 1 was used

for weekdays and design day. Profile 2 was used for weekends and holidays. Since the building was a classroom building, the offices in the building were assumed to follow the same schedule as the classes. No schedules were assumed for unconditioned spaces.

(d) The assumption on 'Activity Level' for various spaces is shown in Appendix C10.

(e) An important assumption regarding the electrical equipment load in the Cosmetology Lab was that the maximum electrical wattage that was input was 11kW instead of the 117 kW as shown in Appendix C3. This assumption was made because of the fact that around 90% of the maximum electrical rating of this space was used in heating water and other fluids that went down the drain. Energy leaving the building in such a fashion does not significantly contribute to cooling loads.

(f) In calculation of 'Overhead Lighting' loads, it was assumed that the Ballast Multiplier was 1.00. In case of T12 fixtures, one ballast was considered for a maximum of two lamps

(g) The 'Outside Surface Color' of the exterior walls was assumed to be 'Medium', which automatically considered an absorptivity of 0.675.

Layers: Inside to Outside	Thickness in	Density lb/ft³	Specific Ht. BTU/lb/F	R-Value hr-ft²-F/BTU	Weight lb/ft²
Inside surface resistance	0.000	0.0	0.00	0.68500	0.0
Gypsum board	0.500	50.0	0.26	0.44803	2.1
Air space	0.000	0.0	0.00	0.91000	0.0
8-in HW concrete	8.000	140.0	0.20	0.66667	93.3
Styrofoam Insulation	1.000	65.5	0.00	5.00000	5.5
Air space	1.000	0.0	0.00	0.91000	0.0
4-in face brick	4.000	125.0	0.22	0.43290	41.7
Outside surface resistance	0.000	0.0	0.00	0.33300	0.0
Totals	14.500			9.39	142.5

Overall U-Value: 0.107 BTU/hr/ft²/F

Figure 4.2: Building 'C' Exterior Wall Construction

(h) Since the construction charts with the data about the windows were not obtained, the 'Overall U-Value' of the windows was assumed to be 0.588 $\frac{\text{BTU}}{\text{hr-ft}^2\text{-}^{\text{O}}\text{F}}$ and the 'Overall Shade Coefficient' was assumed to be 0.887.

(i) Since 'Roof' was defined in the software as 'surface facing the sky', no values were provided for the spaces on first floor. There was no provision for providing the internal ceiling data in the software. In case of the second floor spaces, the 'Skylight Quantity' for the roofs was assumed to be zero. The 'Outside Surface Color' of the roof was assumed to be 'Light' which automatically considered the value of absorptivity as 0.45.

Layers: Inside to Outside	Thickness	Density	Specific Ht.	R-Value	Weight
	in	lb/ft³	BTU/lb/F	hr-ft²-F/BTU	lb/ft²
Inside surface resistance	0.000	0.0	0.00	0.68500	0.0
1/2-in gypsum board	0.500	50.0	0.26	0.44803	2.1
R-14 board insulation	2.000	2.0	0.22	13.88889	0.3
Elastomeric Coating	0.300	71.6	0.35	0.26596	1.8
Outside surface resistance	0.000	0.0	0.00	0.33300	0.0
Totals	2.800			15.62	4.2
			Overall U-Value:	0.064	BTU/hr/ft²/F

Figure 4.3: Building 'C' Roof Construction

(j) The 'Floor Type' was considered to be 'Slab Floor On Grade' for the first floor spaces and 'Floor Above Conditioned Space' for second floor spaces. An 'Edge Insulation R-value' of 10 $\frac{\text{hr-ft}^2\text{-}^{\text{O}}\text{F}}{\text{Btu}}$ was assumed. As calculated from the construction charts, the 'Total Floor U-value' was 0.67 $\frac{\text{BTU}}{\text{hr-ft}^2\text{-}^{\text{O}}\text{F}}$.

(k) It was assumed that no unconditioned partitions were present.

4.2.3 Assumptions related to 'Air Systems'

(a) The Ventilation Sizing Method assumed was 'Sum of space OA airflows'.

(b) The unoccupied space damper position was assumed to be in 'Closed'.

(c) An outdoor Air CO_2 Level of 400 ppm was assumed. (Which was a default value)

(d) The systems were assumed to not have Economizer, Vent. Reclaim, Precool Coil, Humidification and Dehumidification equipment.

(e) The AHUs had heating coils before the cooling coils. However, the software did not have an option of specifying this arrangement by giving the design heating temperature. Therefore the heating was split up into two parts. The first part being a 'Preheat Coil', placed downstream of mixing point which heated the outdoor air to 50^{O}F and the second one being a 'Central Heating Coil' which heated the air to a design temperature of 95^{O}F. The heating source was specified as 'Steam'.

(f) A coil bypass factor of 0.1 was assumed. (Which was a default value)

(g) The capacity control for cooling was set to 'Cycled or Staged Capacity, Fan On'.

(h) Preheating, central heating and cooling were assumed to exist throughout the year.

(i) The capacity control for cooling was also set to 'Cycled or Staged Capacity, Fan On'.

(j) The supply fan is assumed to be 'Forward Curved' type.

(k) The return air fan was assumed to be absent. This was because the return air was being driven by the lower pressure being maintained in the Mechanical Rooms as compared to the conditioned spaces.

(l) The Duct Heat Gain and Duct Leakage were assumed to be 0%.

(m) The Cooling T-stat Setpoints were assumed to be:

Occupied: $70^{O}F$ Unoccupied: $85^{O}F$

(n) The Heating T-stat Setpoints were assumed to be:

Occupied: $68^{O}F$ Unoccupied: $60^{O}F$

(o) The T-stat Throttling Range was assumed to be $1.5^{O}F$. (Which was a default value)

(p) The diversity factor was assumed to be 100%. (Which was a default value)

(r) The supply terminals were assumed to be of 'Diffuser' type.

(s) The reheat was assumed to be absent.

(t) The design Chilled Water ΔT was assumed to be $10^{O}F$ and the Hot Water ΔT was assumed to be $20^{O}F$.

(u) For all the simulations, no 'Safety factor' was used for any of Cooling Sensible, Cooling Latent and Heating loads

(v) For the thermostat schedule, the spaces were assumed to be occupied from 6:00 AM to 6:00 PM on all weekdays and the design day. For weekends and holidays, the spaces were assumed to be unoccupied.

(w) The design supply temperatures for the first four simulations were assumed to be the Leaving Dry Bulb Temperatures (LDB) as shown in Appendix C2. For the Computer Recommended System design, the supply temperature was assumed to be $58^{O}F$.

4.2.4 Assumptions related to ‘Plants’

A steam boiler plant and a chiller plant were assumed to serve the building.

<u>Boiler Plant</u>

(a) The ‘Boiler Sizing’ was set to ‘Auto-Sized Boiler Capacity’ with a capacity oversizing factor of 25%. (Which were default selections)

(b) The ‘Overall Efficiency’ of the boiler was assumed to be 80%.

(c) The fuel Type was set to Fuel Oil.

(d) Boiler accessories were assumed to be absent.

(e) The ‘Part Load Model’ of ‘Constant Efficiency’ was selected.

(f) Hot water flow rate of 5 gpm was assumed.

(g) The distribution system was assumed to be ‘Primary Only, Constant Speed’ with a Coil ΔT of $20^{O}F$ and a ‘Pipe Heat Loss Factor’ of 0%.

(h) The fluid was assumed as ‘Fresh Water’ with a density of 60.6 $\frac{lb}{ft^3}$ and a specific heat of $1\frac{BTU}{lb\text{-}^{O}F}$.

<u>Chiller Plant</u>

(a) The ‘Chiller Sizing’ was set to ‘Auto-Sized Chiller Capacities’ with a Capacity Oversizing Factor of 15%.

(b) The cooling tower configuration was set to ‘One tower for each water-cooled chiller’.

(c) The ‘Plant Control’ was assumed to be ‘Equal Unloading’ and the LCHWT was set to be a constant at a designed value of $44^{O}F$.

(d) The 'Chiller Type' was set to A/C Packaged Reciprocating.

(e) The Full Load Power was assumed to be $1.15 \frac{\text{kW}}{\text{Ton}}$.

(f) The Cooler Flow Rate was assumed to be $2.4 \frac{\text{gpm}}{\text{Ton}}$.

(g) For designing the cooling tower, 'Cooling Tower Model' method was adopted. The design parameters for this were assumed as following.

Condenser Water Flow Rate = $3.0 \frac{\text{gpm}}{\text{Ton}}$

Condenser Pump = $19 \frac{\text{W}}{\text{gpm}}$ (Default Value)

Condenser Pump Mechanical and Electrical efficiency = 100%

Design Wet Bulb =78^{O}F

Range at Design = 10^{O}F

Design Approach = 7^{O}F

Full Load Fan kW = $0.1 \frac{\text{kW}}{\text{Ton}}$

(h) The type of Minimum Set Point Control was set to 'Fan Cycling'.

(i) The distribution system was assumed to be 'Primary Only, Constant Speed' with a Coil ΔT of 20^{O}F and a 'Pipe Heat Gain Factor' of 0%.

(j) The fluid was assumed to be 'Fresh Water' with a density of $62.4 \frac{\text{lb}}{\text{ft}^3}$ and a specific heat of $1 \frac{\text{BTU}}{\text{lb -}^{O}\text{F}}$.

4.2.5 Assumptions related to 'Buildings'

(a) The major assumptions made in this category were regarding the rate schedules of the electric and fuel oil meters. Simple schedules were selected for both the meters, the details of which are shown in Fig. 4.4. The average data was obtained from online sources [5].

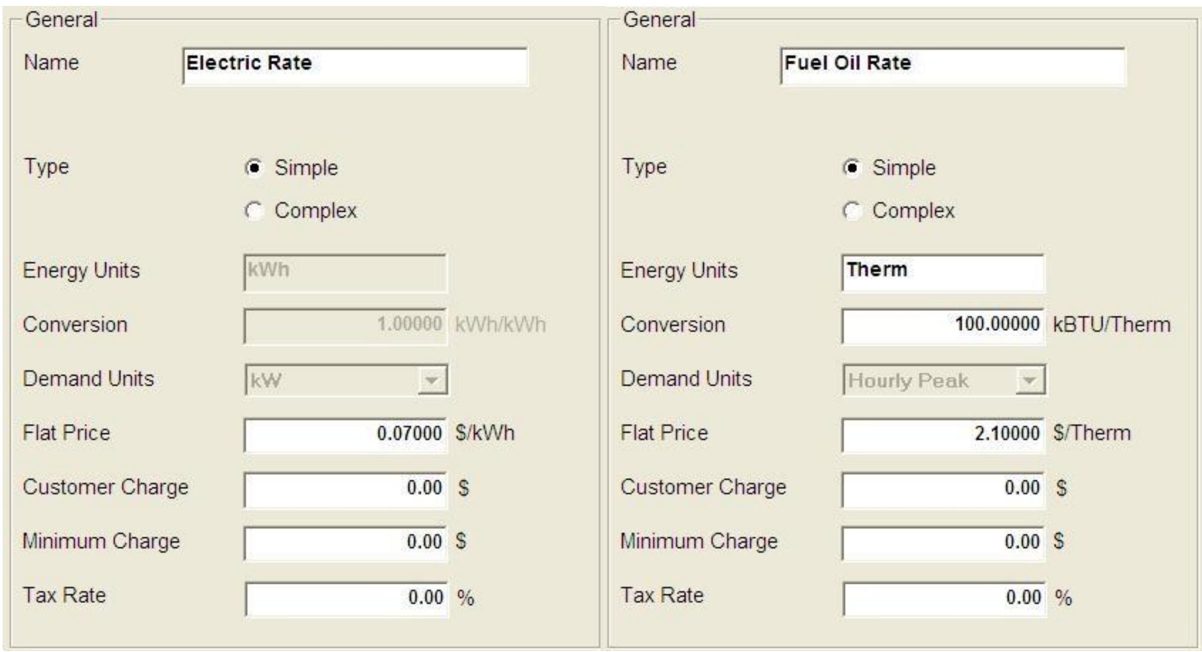


Figure 4.4: Rate Schedules

(b) An 'Average Building Power Factor' of 100% was assumed. (Default Value)

(c) A 'Source Electric Generating Efficiency' of 28% was assumed. (Default Value)

4.3 PROCEDURE FOR RUNNING SIMULATIONS

The mechanical charts specify original design supply and outside air CFMs (Appendix C2). The results of testing conducted by 'Palmetto Air & Water Balance' gave different values (Appendix C6). All supply air (SA) CFMs were not measured by 'Palmetto Air & Water Balance'. Therefore it was imperative to decide on these inputs.

4.3.1 Estimation of Unmeasured Supply Air CFMs

(a) First, the SA CFMs which were measured were considered along with the total area of the spaces they served.

(b) Then the design CFMs obtained from the mechanical charts were considered for the same spaces.

(c) The percentage deviation (D) of the measured values from the design values was calculated.

$$\text{\% Deviation (D)} = \frac{\text{(Design SA CFM) - (Measured SA CFM)}}{\text{(Design SA CFM)}} \times 100$$

(d) The area weighted average (D_A) of these percentage deviations was calculated to obtain the average error.

$$\text{Area Weighted Average Deviation } (D_A) = \frac{\sum (D_{\text{Space}} \times \text{Area}_{\text{Space}})}{\sum \text{Area}_{\text{Space}}}$$

(e) Using the design CFMs and the D_A, the Unmeasured SA CFMs (U) were estimated.

$$\text{Unmeasured SA CFM (U)} = \text{Design SA CFM} \times \left(1 - \frac{D_A}{100}\right)$$

The values regarding the estimation are shown in Appendix C11.

4.3.2 Estimation of Outside Air CFM, Direct Exhaust and Infiltration

Another issue to be addressed was deciding on the infiltration and direct exhaust rates to be input into HAP. It can be observed from Appendix C6 that the total OA was 2589 CFM. In order to study the effect of relative pressurization of building with respect to the ambient conditions, three simulation runs were made by using Total OA as a variable. In all the cases, the selected Total OA CFM was split up among the AHUs based on the magnitude of areas that they served.

$$\text{OA CFM of an AHU} = \frac{\text{(Area Served by the AHU)}}{\text{(Total Area of Conditioned Spaces)}} \times \text{(Total OA CFM)}$$

For providing space OA CFM values, a similar approach was followed using the space areas.

$$\text{OA CFM of a space} = \frac{\text{(Area of the Space)}}{\text{(Total Area of Conditioned Spaces)}} \times \text{(Total OA CFM)}$$

The details of these runs are as follows.

Table 4.1: Total OA CFM for various runs

Simulation No.	Total OA CFM	Remark
1	2589	Positive Pressurization
2	1652	No Pressurization
3	1000	Negative Pressurization

Positive Pressurization Case:

(a) In this case, there was no uncontrolled infiltration.

(b) Since the OA CFM was greater than the total exhaust flow (measured by 'Palmetto Air & Water Balance'), there had to be some way in which the remainder of OA CFM that entered had to escape from the building. This should generally happen through exfiltration. As there was no option of exfiltration in HAP, this input data had to be given in form of direct exhaust from the spaces in the AHUs.

The difference between the OA CFM and exhaust flow CFM was split up among the AHUs which did not have any exhaust flow, based on the OA CFM to these AHUs. This step was taken to justify the fact that the excessive OA in the rooms would distribute to other spaces in the building (a path for which there is lesser resistance) rather than escape outside from the same space. The values thus obtained were given as the 'Direct Exhaust' input to the respective AHUs.

Direct Exhaust from an AHU (No Exhaust flow) =

$$\frac{\text{(OA CFM to AHU)}}{\text{(Total OA CFM to non exhausting AHUs)}} \times \text{(Total OA CFM - Exhaust Flow CFM)}$$

(c) The input data concerning Simulation 1 are shown in Appendices C12 and C13.

No Pressurization Case:

(a) In this case there was no uncontrolled infiltration.

(b) Since total OA CFM was being exhausted by the exhaust flows (measured by 'Palmetto Air & Water Balance'), there was no additional Direct Exhaust from other AHUs.

(c) The input data concerning Simulation 2 are shown in Appendices C14 and C15.

Negative Pressurization Case:

(a) As a first step, the OA CFMs were subtracted from the Forced Exhaust Air Flows for each AHU.

(b) If this value was positive, it meant that the AHU was still exhausting the resulting amount of air from the building.

(c) The negativity of this value represented the escape of air from that AHU to other parts of the building.(lesser resistance paths)

(d) The total OA CFM was subtracted from the total Forced Exhaust Air Flow. The resulting value was split up among the AHUs with positive individual differences. The split-up values were then divided among the corresponding spaces on basis of their area and were given as infiltration inputs.

(e) Direct exhausts existed only for the specified AHUs. (measured by 'Palmetto Air & Water Balance')

(f) The input data concerning Simulation 3 are shown in Appendices C16, C17 and C18.

4.3.3 Other Simulations

Two more simulations were run with the following parameters.

(a) Simulation 4: The design data from the mechanical charts was directly input into HAP 4.5 to study the system as originally designed. The exhaust flows determined by 'Palmetto Air & Water Balance' was utilized here. The design data gave rise to a positively pressurized building, the input data of which are shown in Appendices C19 and C20. During the calculation of direct exhaust, a number of building air balance iterations showed that in order to avoid relative interior pressurization, distribution of air within a building should occur such that the direct exhaust from area served by an AHU would be equal to the OA CFM for that particular AHU. The procedure followed for air balance was the same as used in 'Simulation 1'. However, in this case all the AHUs were involved in the calculation since the total direct exhaust was relatively smaller than the OA CFM.

(b) Simulation 5: In this simulation, the 'Supply Temperature' input was considered to be 58^{O}F and the exhaust flows (measured by Palmetto Air & Water Balance) were input into HAP 4.5 to generate a computer modeled system for the building. In this case, the OA CFM used was input into the space data by specifying the preexisting nature of spaces. Designations were given to the nature of space usage for convenience as shown in Table 4.2. The input data for this simulation has been shown in Appendices C21 and C22.

Table 4.2: OA CFM Designation of 'Space Usage'

OA Designation	Space Usage for OA CFM Requirements	CFM/Person	CFM/ft^2
O 1	EDUCATION: Classroom (age 9+)	10	0.12
O 2	EDUCATION: Daycare Sick Room	10	0.18
O 3	EDUCATION: Science Laboratory	10	0.18
O 4	GENERAL: Break Room	5	0.06
O 5	GENERAL: Conference/ Meeting	5	0.06
O 6	GENERAL: Corridor	-	0.06
O 7	GENERAL: Storage Room	-	0.12
O 8	MISCELLANEOUS: Computer (Not Printing)	5	0.06
O 9	MISCELLANEOUS: Electrical Equipment Room	-	0.06
O 10	MISCELLANEOUS: Elevator Machine Room	-	0.06
O 11	OFFICE: Main Entry Lobby	5	0.06
O 12	OFFICE: Office Space	5	0.06
O 13	OFICE: Reception Area	5	0.06

$\frac{\text{CFM}}{\text{Person}}$ and $\frac{\text{CFM}}{\text{ft}^2}$ values have been obtained from ASHRAE Std. 62.1 – 2004. (2)

CHAPTER 5: RESULTS AND DISCUSSIONS

5.1 RESULTS

Building ‘C’ in Brunswick Community College was modeled as described in Chapter 4. Each one of the five simulations performed resulted in 100 reports (5 for design of each of the 18 air handling units, 2 for the plants and 8 for the building energy use). Of all these reports, only 11 of them were selected to illustrate the general set of reports that was generated. AHU 8 was selected to illustrate the ‘AHU Design results’ because of the availability of preheat in this system design. Illustrative reports have been shown in Appendices D1 to D11.

Once all the simulations had been performed, the results obtained were summarized for each simulation based four parameters (Refer to Appendices D12 through D16). These parameters were:

(a) Maximum Zone Dry Bulb Temperatures for each AHU (^{O}F)

(b) Resulting Relative Humidity (%)

(c) Cooling Coil Load (Tons)

(d) Heating Coil Load (MBH)

Using the above parameters, the results were then compared between the AHUs serving the same zones in each run. The plots of these comparisons are shown in Appendices D17 through D20.

Finally, the annual HVAC costs of simulations were recorded (Table 5.1) and compared (Appendix D21).

Table 5.1: Annual HVAC Costs in each Simulation

Run	Annual HVAC Cost
1	$26,441.00
2	$26,464.00
3	$26,284.00
4	$26,771.00
5	$27,376.00

5.2 COMMENTS ON RESULTS

(a) Understanding the results of all the simulations demanded the compaction of the plethora of data that was generated from them. Also, the results were best understood when put to comparison rather than in individual studies. Therefore the comparison of comfort factors (viz. Maximum Zone Dry Bulb Temperature and Resulting Relative Humidity), Cooling Coil Loads, Heating Coil Loads and the Annual HVAC Costs was performed.

(b) Simulation 1

(1) 'The Maximum Zone Dry Bulb Temperature' for the AHUs ranged from 74.5^{O}F to 99.4^{O}F. These values were quite off from the cooling set point of 70^{O}F.

(2) The 'Resulting Relative Humidity' of the AHUs was generally in the range of 20% to 53% except in the case of AHU 6 where it was 71%. In general these values of relative humidities were on the lower side of the comfort values of 55-65%.

(3) The total cooling load was observed to be 106.6 Tons. This value exceeded the actual chiller capacity of 100 Tons by 6.6%.

(4) The total heating load was observed to be 111.5 MBH which was way less than the actual capacity of boiler that was installed (579 MBH).

(c) Simulation 2

(1) The 'Maximum Zone Dry Bulb Temperature' values for the AHUs were the same as Simulation 1.

(2) The ‘Resulting Relative Humidity’ of the AHUs was generally in the range of 20% to 53% except in the case of AHU 6 where it was 71%. In general these values of relative humidities were on the lower side of the comfort values of 55-65%.

(3) The total cooling load was observed to be 103 Tons. This value exceeded the actual chiller capacity of 100 Tons by 3%.

(4) The total heating load was observed to be 70.7 MBH which was way less than the actual capacity of boiler that was installed (579 MBH).

(d) <u>Simulation 3</u>

(1) The ‘Maximum Zone Dry Bulb Temperature’ values for the AHUs were the same as Simulation 1.

(2) The ‘Resulting Relative Humidity’ of the AHUs was generally in the range of 9.7% to 49% except in the case of AHU 6 where it was 71%. In general these values of relative humidities were on the lower side of the comfort values of 55-65%.

(3) The total cooling load was observed to be 102.3 Tons. This value exceeded the actual chiller capacity of 100 Tons by 2.3%.

(4) The total heating load was observed to be 63.9 MBH which was way less than the actual capacity of boiler that was installed (579 MBH).

(e) Simulation 4

(1) 'The Maximum Zone Dry Bulb Temperature' for the AHUs ranged from 76.4^{O}F to 98^{O}F. These values were quite off from the cooling set point of 70^{O}F.

(2) The 'Resulting Relative Humidity' of the AHUs was generally in the range of 22% to 51% except in the case of AHU 6 where it was 71%. In general these values of relative humidities were on the lower side of the comfort values of 55-65%.

(3) The total cooling load was observed to be 118.1 Tons. This value exceeded the actual chiller capacity of 100 Tons by 18.1%.

(4) The total heating load was observed to be 210.2 MBH which was less than the actual capacity of boiler that was installed (579 MBH).

(f) Simulation 5

(1) 'The Maximum Zone Dry Bulb Temperature' for the AHUs ranged from 71.5^{O}F to 71.8^{O}F. These values were pretty close to the designed set points.

(2) The 'Resulting Relative Humidity' of the AHUs was generally in the range of 55% to 65%. These values indicated quite comfortable conditions.

(3) The total cooling load was observed to be 168.1 Tons. This value exceeded the actual chiller capacity of 100 Tons by 68.1%.

(4) The total heating load was observed to be 497.4 MBH which was less than the actual capacity of the installed boiler (579 MBH) by only 14%.

(g) Comparison of the ‘Maximum Zone Dry Bulb Temperature’ and ‘Resulting Relative Humidity’ for all the simulations indicated that the capacities of the systems in simulations 1 – 4 were inadequate to produce the adequate comfort conditions. However, simulation 5 resulted in a system that could effectively maintain the desired conditions.

(h) Comparison of the total cooling loads for all the simulations shows an increasing tend from negative pressurization of the building to positive pressurization. This can be attributed to the fact that attaining positive pressurization requires more outside air to pass through the conditioning system in order to achieve the desired conditions.

(i) On comparison of heating loads, a similar trend to cooling loads is observed. The same explanation can be utilized to explain this situation.

(j) Examination of the annual cost of operation of the HVAC systems (Table 5.1) revealed that for a given set of SA CFM, the ‘Annual HVAC cost’ first increased from negative to no pressure situation and then decreased only slightly for positive pressurization. Furthermore, it was also be observed that when the SA and OA CFMs were increased (in turn positively pressurizing the building), the costs increased. However it should be noticed that this had to be done in order to bring the systems to acceptable performance levels.

5.3 INCONSISTENCIES IN HAP 4.5

The point that could be agreed upon (as understood from the visits and simulations) was the fact that the current capacity of the Air Handling systems was inadequate to produce the desired comfort conditions. Though HAP 4.5 did not give out the exact figures of the temperatures and humidities as observed in the zones, it did provide a general idea of how the various parameters might change. However some inconsistencies in HAP 4.5 cannot be neglected. They are as follows:

(a) Even though the values of direct exhausts were varied for any given set of SA and OA CFMs, the results obtained were not different in any aspect. This caused a concern about the credibility of the results. An attempt to understand this situation led to the following extract (Pg. 90 – 91) from the 'HAP 4.5 Contents Help' menu.

"Direct Exhaust Airflow defines the airflow rate for direct exhaust. This flow rate is assumed to occur for any hour in which the central supply fan is ON and the ventilation dampers are open. Direct exhaust airflow should be less than or equal to the outdoor ventilation rate for the system.

If direct exhaust airflow does not exist in the system, specify a zero airflow rate. When this is done, the program will assume any outdoor ventilation air is exhausted after flowing through the return duct or plenum. During system design calculations, if the direct exhaust airflow rate for zones in a system exceeds the outdoor ventilation airflow,

the design ventilation airflow rate will be increased to equal the direct exhaust airflow rate. During simulation of system operation using proportional, scheduled or demand controlled ventilation control, it is possible for ventilation airflow to fall below the direct exhaust airflow for zones in the system. In such a situation, direct exhaust airflow is reduced since total system exhaust cannot exceed ventilation."

This extract showed that it was not possible to create a net pressure in the building because of the tendency of the program to balance out the building's pressure. Given any set of SA and OA CFMs, there would be no change in results regarding the capacity of a system.

(b) Another point which caused concern was the result "Psychrometric Analysis of AHUs". (Appendix D5). This result showed an incorrect cooling process on the charts. If this were indeed the case, the load calculations and the state points would be incorrect.

The absence of 'email help' option on the Carrier HAP website and the only available help being periodic troubleshooting documents, made attempts to pursue these discussions futile.

5.4 CONCLUSION

Over time, visits were made to Brunswick Community College to determine the causes responsible for prevailing discomfort in Building ‘C’. Progress was made and new issues discovered on every visit. The building was modeled and simulations were run using HAP 4.5 to understand the variation in performance of the HVAC system serving the building. It was also observed that the variations in relative pressurization of the building affected the energy performance up to 0.59% in terms of annual cost with costs first increasing from positive pressurization to no pressurization and then decreasing to negative pressurization. A comparison with the actual design system obtained from the original plans was also performed. Finally a system as suggested by the software, with comfort conditions as parameters, was included in the comparison. It was observed that the use of this system increased the annual operation cost by 4.15% as compared to the current system while providing the required comfort conditions.

The possibility of the system being under sized was brought to light and various plausible reasons were pondered upon during the entire course of work.

Ultimately, it could be positively asserted that each step has brought us closer to the ‘Actual Truth’ regarding the system performance.

REFERENCES

1. [Online] http://www.opm.gov/Operating_Status_Schedules/fedhol/2011.asp. 1.

2. *ASHRAE Handbook - Fundamentals.* s.l. : ASHRAE, 2009.

3. [Online] http://www.arca53.dsl.pipex.com/index_files/vent2.htm.

4. [Online] http://www.wunderground.com/history/.

5. [Online] http://www.eia.gov/dnav/pet/pet_pri_wfr_dcus_nus_w.htm.

APPENDICES

APPENDIX A: CASE STUDY RESULTS

A1: Report of AHU Design for Studio A from HAP 4.5

Air System Information

Air System Name	AHU Studio A Actual		Number of zones	1	
Equipment Class	CW AHU		Floor Area	3917.6	ft²
Air System Type	SZCAV		Location	Raleigh/Durham, North Carolina	

Sizing Calculation Information

Zone and Space Sizing Method:

Zone CFM	Sum of space airflow rates		Calculation Months	Jan to Dec	
Space CFM	Individual peak space loads		Sizing Data	User-Modified	

Central Cooling Coil Sizing Data

Total coil load	58.4	Tons	Load occurs at	Jul 1600	
Total coil load	700.7	MBH	OA DB / WB	93.0 / 76.0	°F
Sensible coil load	441.1	MBH	Entering DB / WB	85.9 / 70.9	°F
Coil CFM at Jul 1600	13896	CFM	Leaving DB / WB	56.1 / 54.9	°F
Max block CFM	25000	CFM	Coil ADP	52.8	°F
Sum of peak zone CFM	25000	CFM	Bypass Factor	0.100	
Sensible heat ratio	0.629		Resulting RH	51	%
ft²/Ton	67.1		Design supply temp.	58.0	°F
BTU/(hr-ft²)	178.9		Zone T-stat Check	1 of 1	OK
Water flow @ 10.0 °F rise	140.22	gpm	Max zone temperature deviation	0.0	°F

Central Heating Coil Sizing Data

Max coil load	38.6	MBH	Load occurs at	Des Htg	
Coil CFM at Des Htg	695	CFM	BTU/(hr-ft²)	9.9	
Max coil CFM	25000	CFM	Ent. DB / Lvg DB	40.8 / 93.1	°F
Water flow @ 20.0 °F drop	3.86	gpm			

Supply Fan Sizing Data

Actual max CFM	25000	CFM	Fan motor BHP	20.00	BHP
Standard CFM	24605	CFM	Fan motor kW	14.91	kW
Actual max CFM/ft²	6.38	CFM/ft²			

Return Fan Sizing Data

Actual max CFM	25000	CFM	Fan motor BHP	15.00	BHP
Standard CFM	24605	CFM	Fan motor kW	11.19	kW
Actual max CFM/ft²	6.38	CFM/ft²			

Outdoor Ventilation Air Data

Design airflow CFM	13800	CFM	CFM/person	138.00	CFM/person
CFM/ft²	3.52	CFM/ft²			

A2: Report of AHU Design for Studio B from HAP 4.5

Air System Information

Air System Name	**AHU Studio B Actual**		Number of zones	**1**	
Equipment Class	**CW AHU**		Floor Area	**2748.5**	ft²
Air System Type	**SZCAV**		Location	**Raleigh/Durham, North Carolina**	

Sizing Calculation Information

Zone and Space Sizing Method:

Zone CFM	**Sum of space airflow rates**	Calculation Months	**Jan to Dec**
Space CFM	**Individual peak space loads**	Sizing Data	**User-Modified**

Central Cooling Coil Sizing Data

Total coil load	**46.7**	Tons	Load occurs at	**Aug 1600**	
Total coil load	**560.4**	MBH	OA DB / WB	**93.0 / 76.0**	°F
Sensible coil load	**408.2**	MBH	Entering DB / WB	**84.5 / 72.2**	°F
Coil CFM at Aug 1600	**20000**	CFM	Leaving DB / WB	**65.3 / 64.2**	°F
Max block CFM	**20000**	CFM	Coil ADP	**63.2**	°F
Sum of peak zone CFM	**20000**	CFM	Bypass Factor	**0.100**	
Sensible heat ratio	**0.728**		Resulting RH	**69**	%
ft²/Ton	**58.9**		Design supply temp.	**58.0**	°F
BTU/(hr-ft²)	**203.9**		Zone T-stat Check	**1 of 1**	OK
Water flow @ 10.0 °F rise	**112.14**	gpm	Max zone temperature deviation	**0.0**	°F

Central Heating Coil Sizing Data

Max coil load	**599.0**	MBH	Load occurs at	**Des Htg**	
Coil CFM at Des Htg	**20000**	CFM	BTU/(hr-ft²)	**217.9**	
Max coil CFM	**20000**	CFM	Ent. DB / Lvg DB	**44.1 / 72.3**	°F
Water flow @ 20.0 °F drop	**59.93**	gpm			

Supply Fan Sizing Data

Actual max CFM	**20000**	CFM	Fan motor BHP	**15.00**	BHP
Standard CFM	**19684**	CFM	Fan motor kW	**11.19**	kW
Actual max CFM/ft²	**7.28**	CFM/ft²			

Return Fan Sizing Data

Actual max CFM	**20000**	CFM	Fan motor BHP	**10.00**	BHP
Standard CFM	**19684**	CFM	Fan motor kW	**7.46**	kW
Actual max CFM/ft²	**7.28**	CFM/ft²			

Outdoor Ventilation Air Data

Design airflow CFM	**9700**	CFM	CFM/person	**242.50**	CFM/person
CFM/ft²	**3.53**	CFM/ft²			

APPENDIX B: BUILDING 'C' OBSERVATIONS

B1: Data recorded by Mr. Doug Gunnel on 07/29/2010

Ambient Conditions: Tdb =89.7F, RH = 73.9%

AHU	Room	Supply Air to Room	Room Conditions (via sling)
AHU-2	129	64db, sat	db = 70.8F, RH =74.8%
AHU-3	Disp	67db, sat	db =70.8F, RH =74.7%
AHU-4	123	60db, sat	db = 70.4F, RH =66.8%
AHU-6	115	58db, sat	db =70.2F, RH =64%
AHU-7	105	58db, sat	db =72.1F, RH =68%
AHU-14	211	67db, sat	db =72.1F, RH =74.8%
AHU-15	218,219	67db, sat	db =72.7F, RH = 64.1 %
	225	70db, sat	db =72.9F, RH =75.5%
	229	64db, sat	db =74.4F, RH =65.4%
	231	66db, sat	db =72.4F, RH =64.8%
	233	66db, sat	db =73.7F, RH =64%
	234	65db, sat	db = 73.3F, RH = 65.3%
	235	65db, sat	db = 73.0F, RH = 67.6%
	236	64db, sat	db = 72.8F, RH = 64.8%

B2: Data collected from HOBOS and Online Sources plotted over a Month

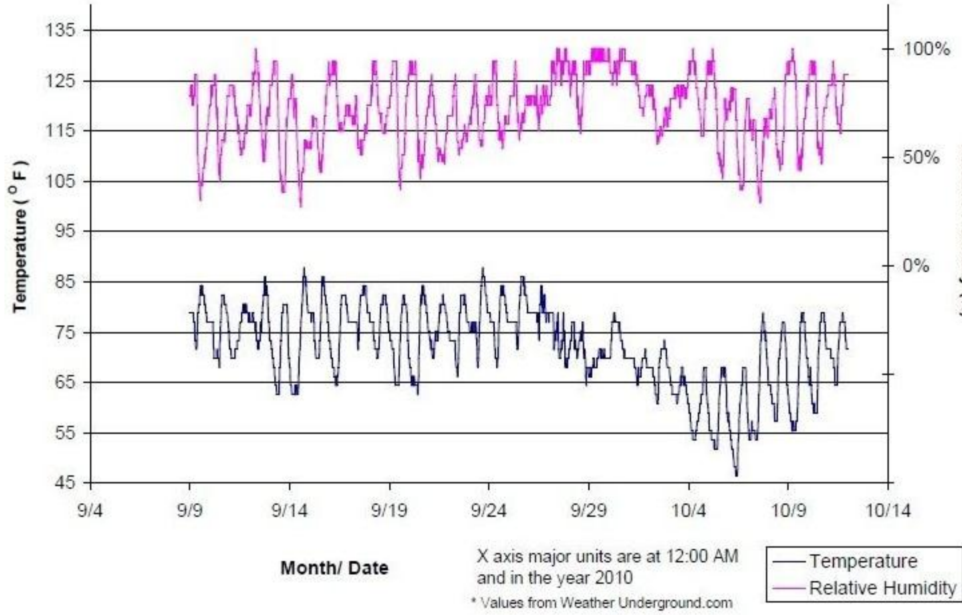


Fig. B2.1: Ambient Conditions in Brunswick County

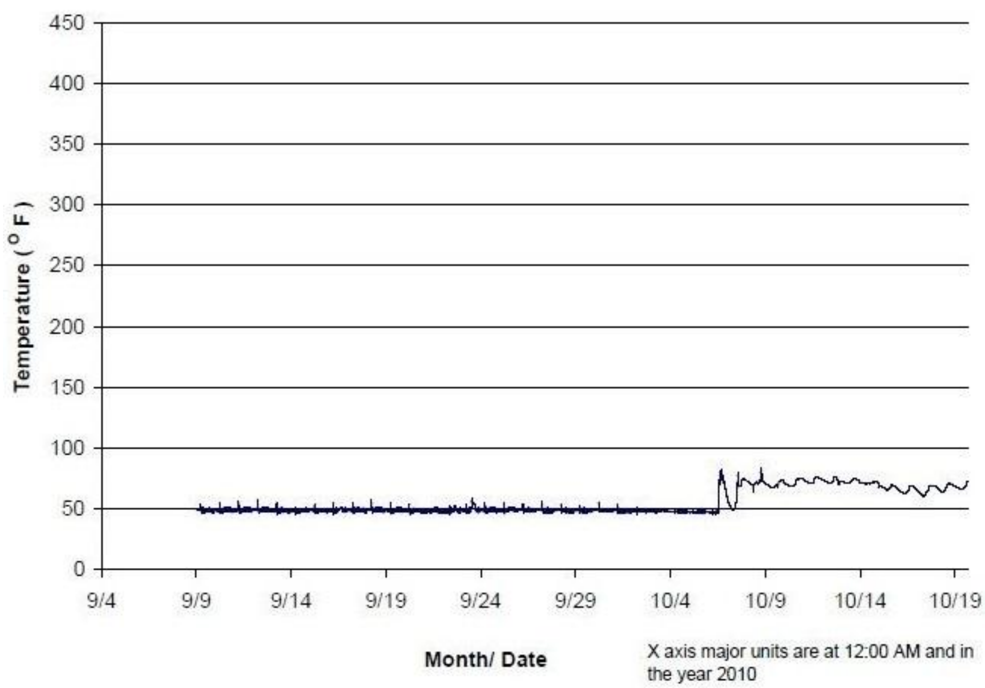


Fig. B2.2: Chiller Water Return Temperature

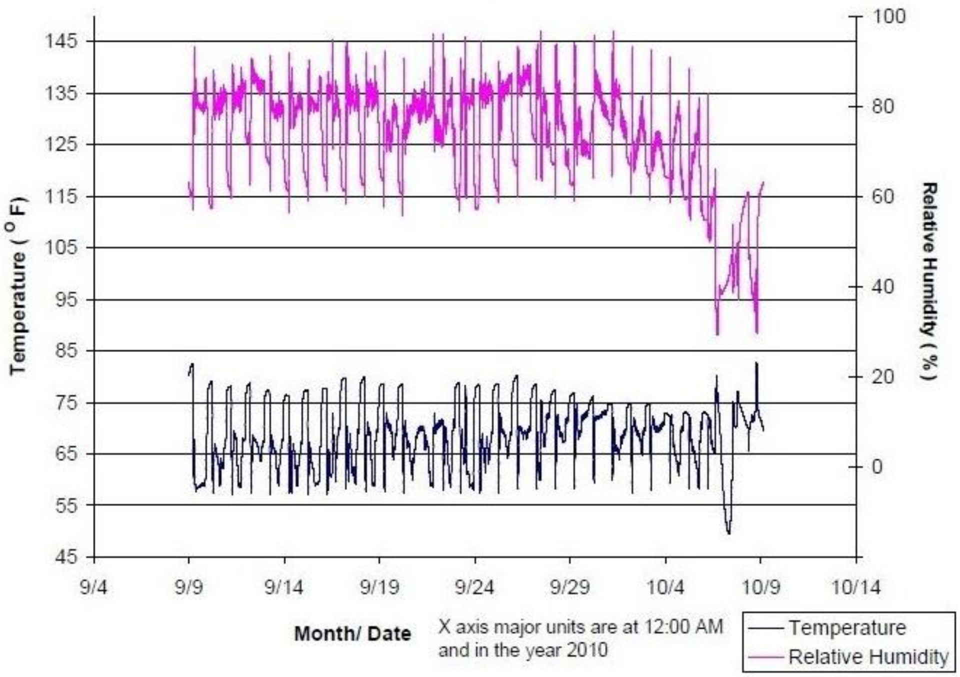


Fig. B2.3: Dr. Snyder's Room (Supply Conditions)

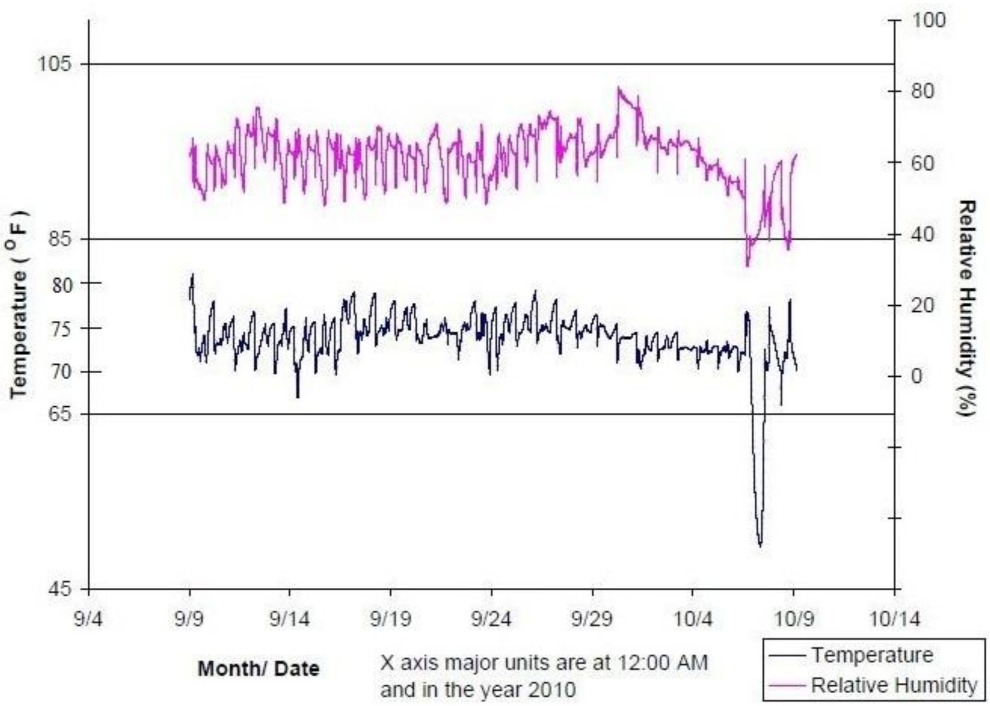


Fig. B2.4: Dr. Snyder's Room (Room Conditions)

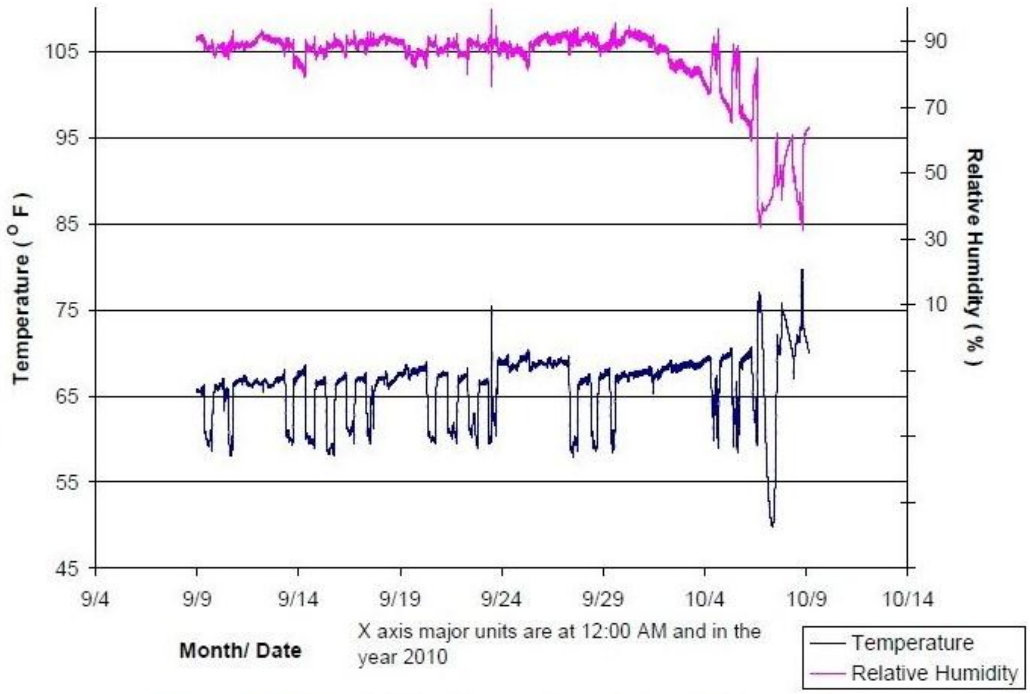


Fig. B2.5: **Room 105 - Science Room (Supply Conditions)**

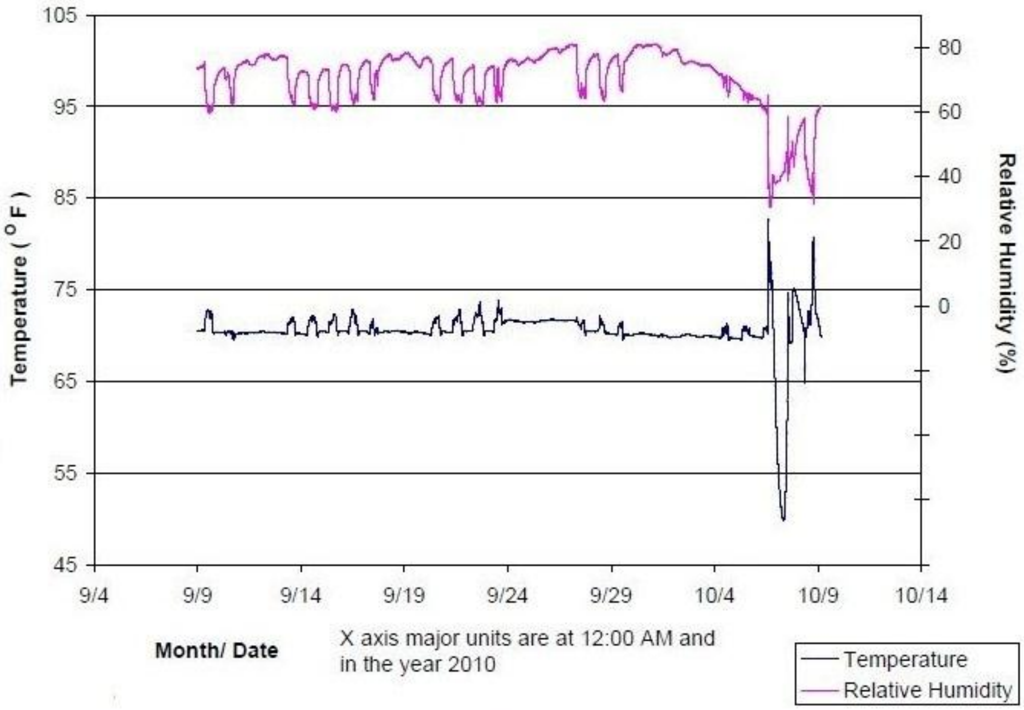


Fig. B2.6: **Room 105 - Science Room (Room Conditions)**

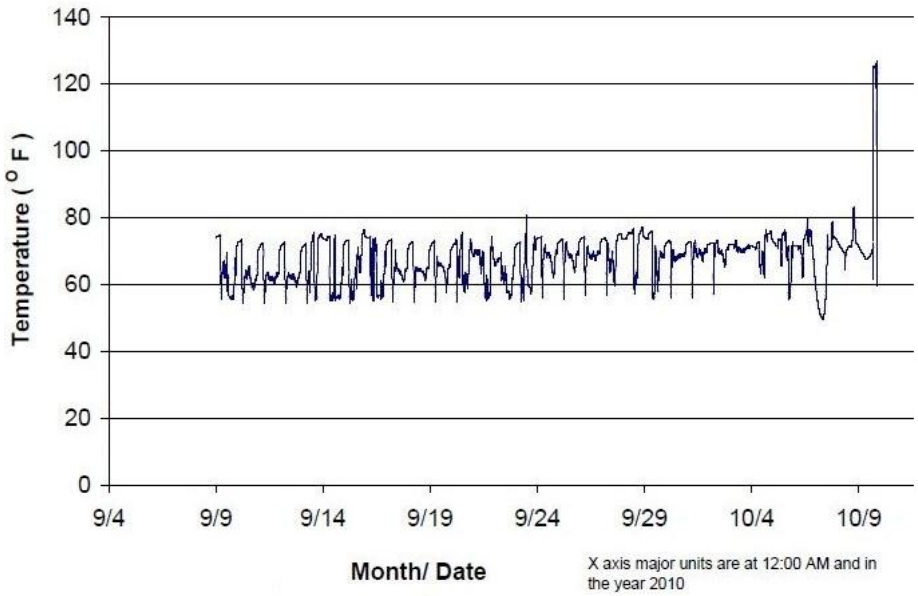


Fig. B2.7: Room 123 - Class Room (Supply Conditions)

NOTE: The HOBO that was used to obtain the data above did not record Supply Air Relative Humidity.

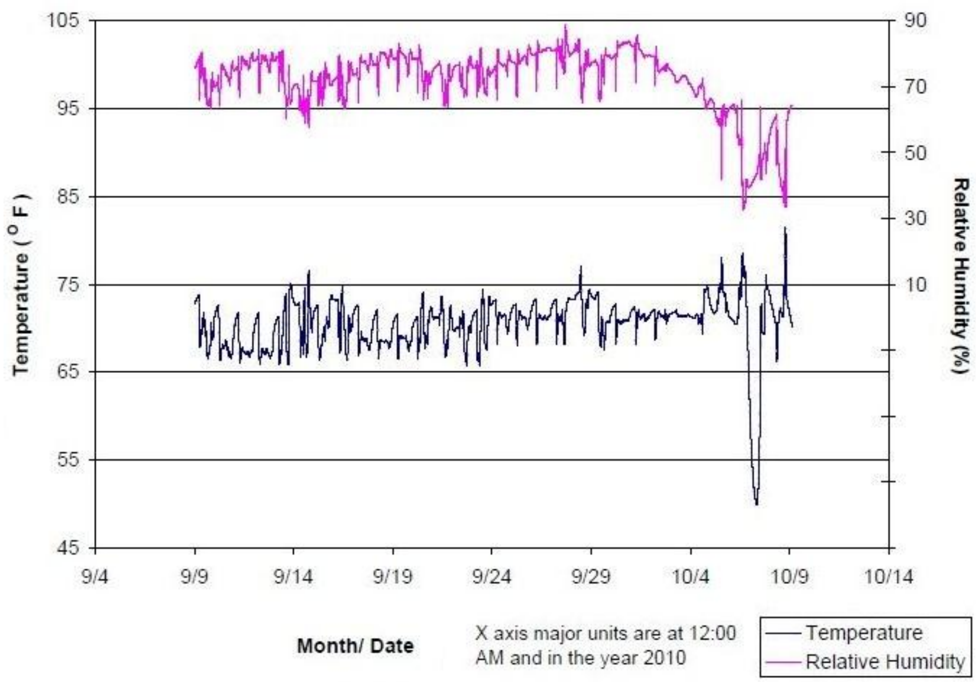


Fig. B2.8: Room 123 - Class Room (Room Conditions)

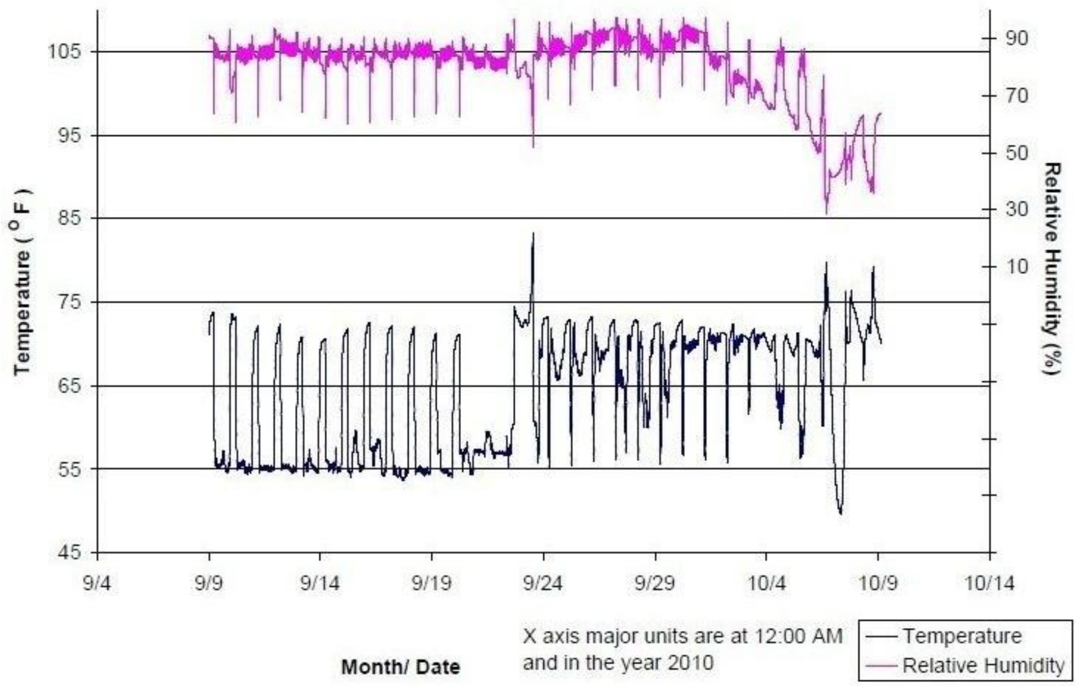


Fig. B2.9: Room 139 - Cosmetology Room (Supply Conditions)

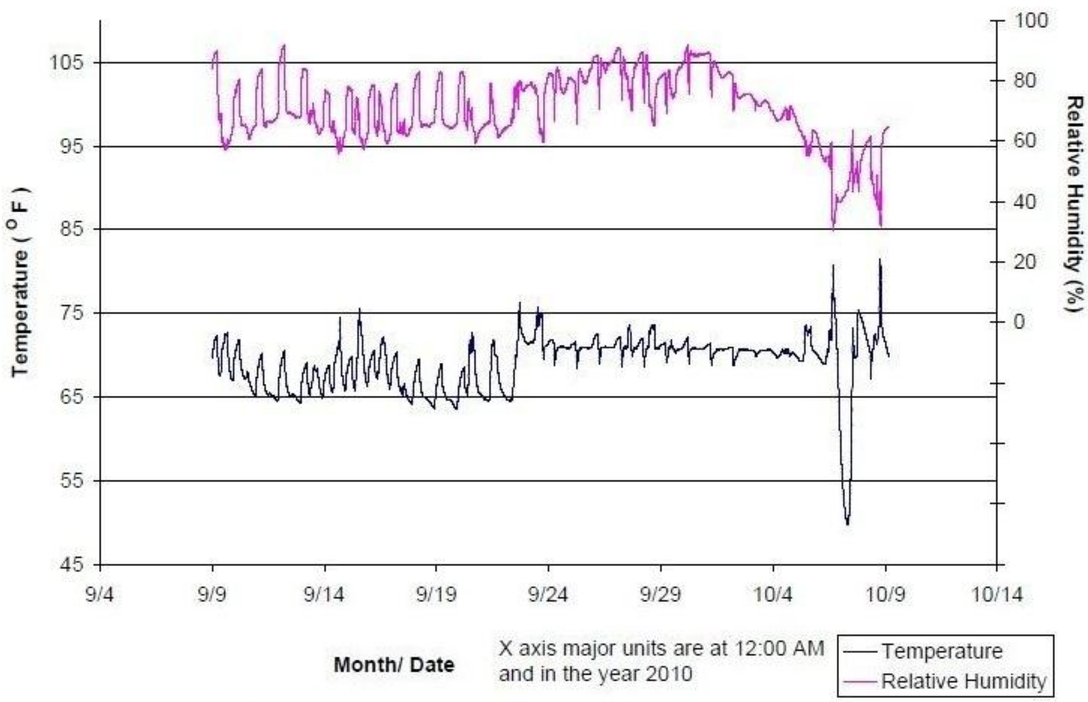


Fig. B2.10: Room 139 - Cosmetology Room (Room Conditions)

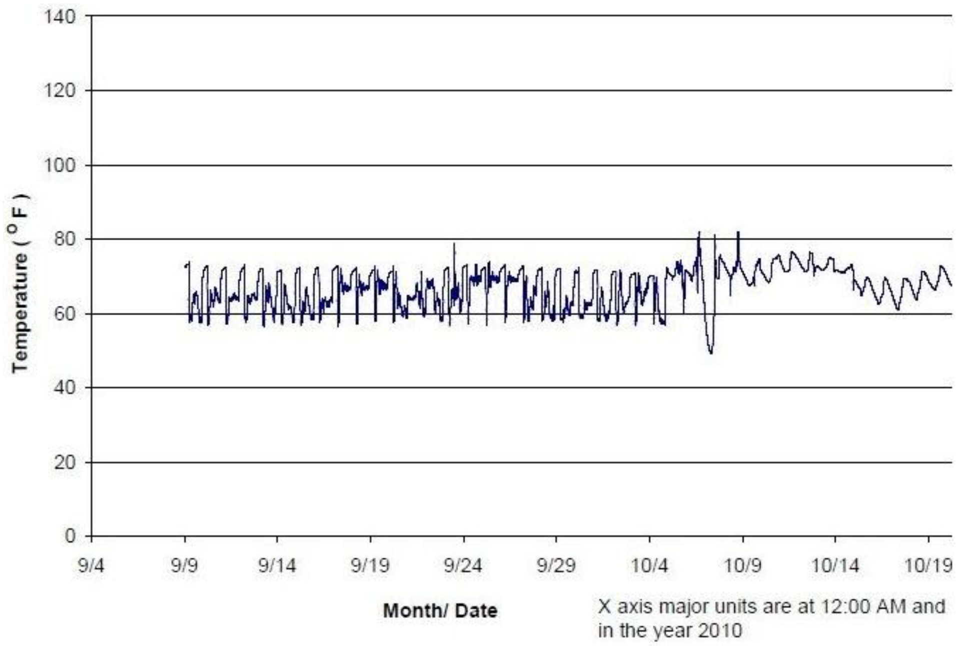


Fig. B2.11: Room 135 - Geography Room (Supply Conditions)

NOTE: The HOBO that was used to obtain the data above did not record Supply Air Relative Humidity.

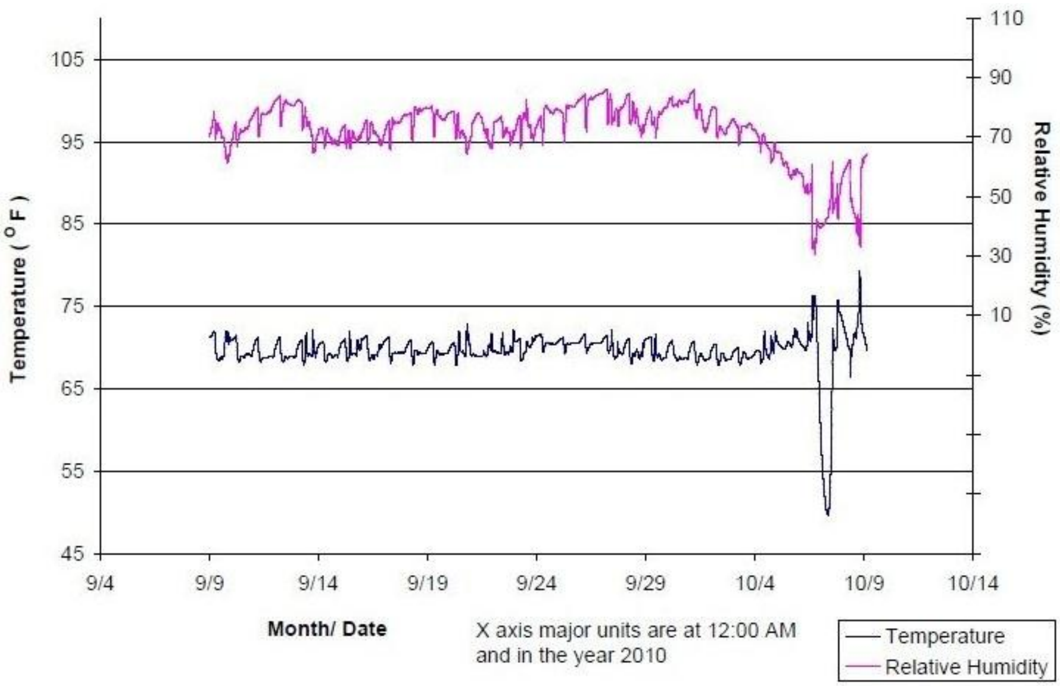


Fig. B2.12: Room 135 - Geography Room (Room Conditions)

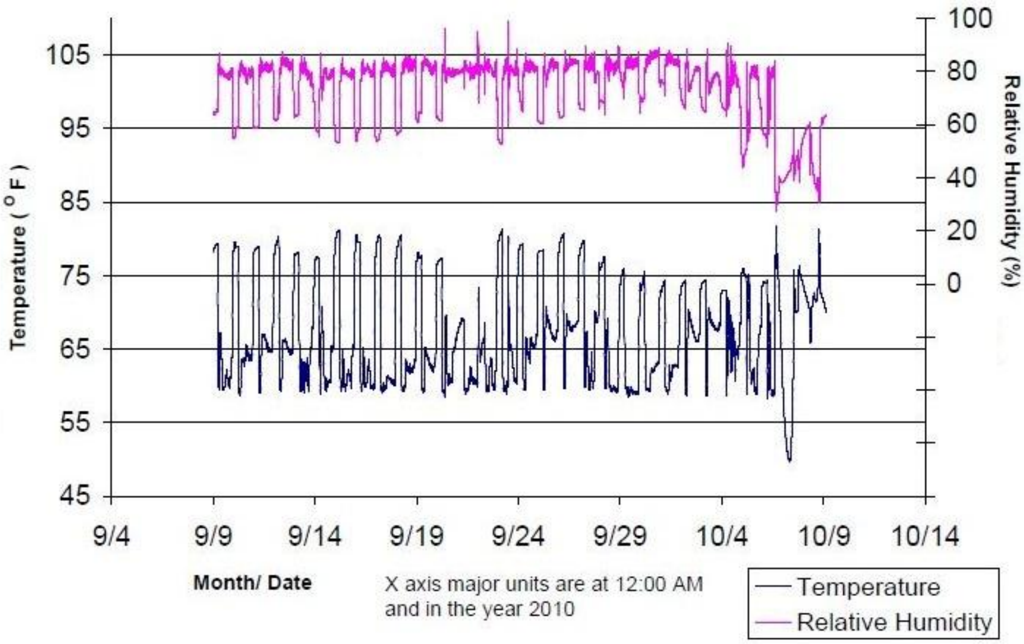


Fig. B2.13: Room 209 - Computer Room (Supply Conditions)

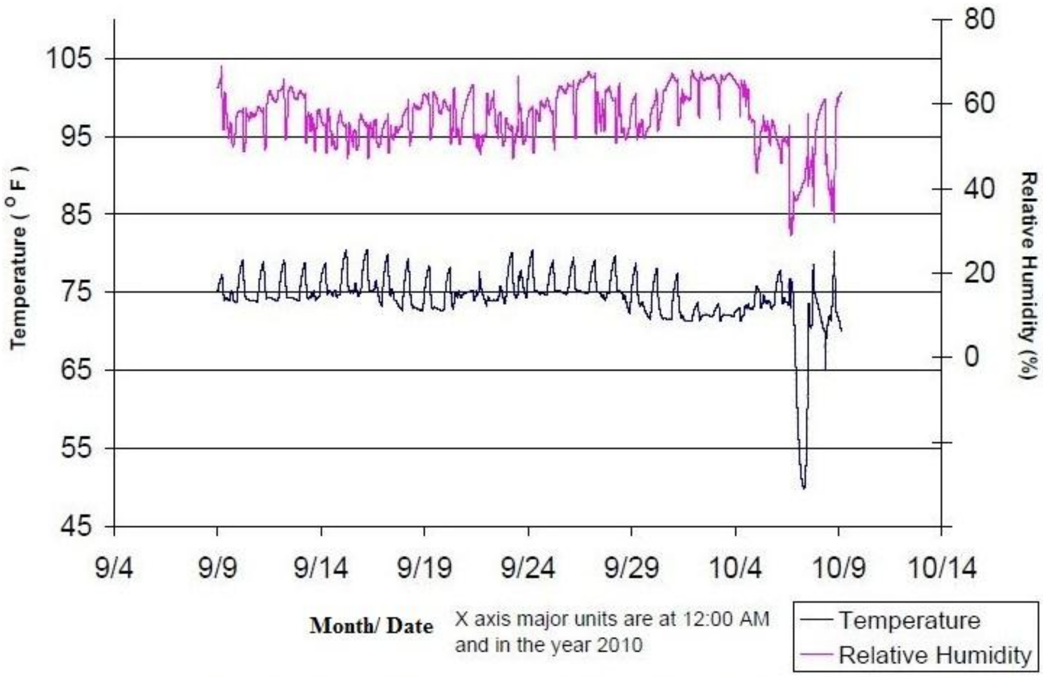


Fig. B2.14: Room 209 - Computer Room (Room Conditions)

B3: Data collected from HOBOS and Online Sources plotted over a Week

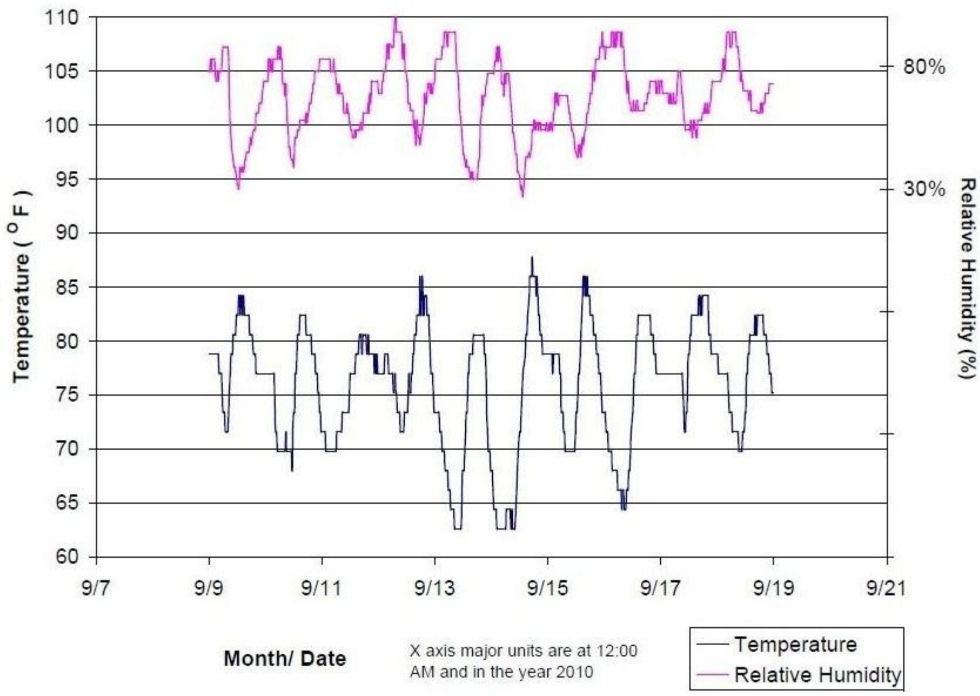


Fig. B3.1: Ambient Conditions

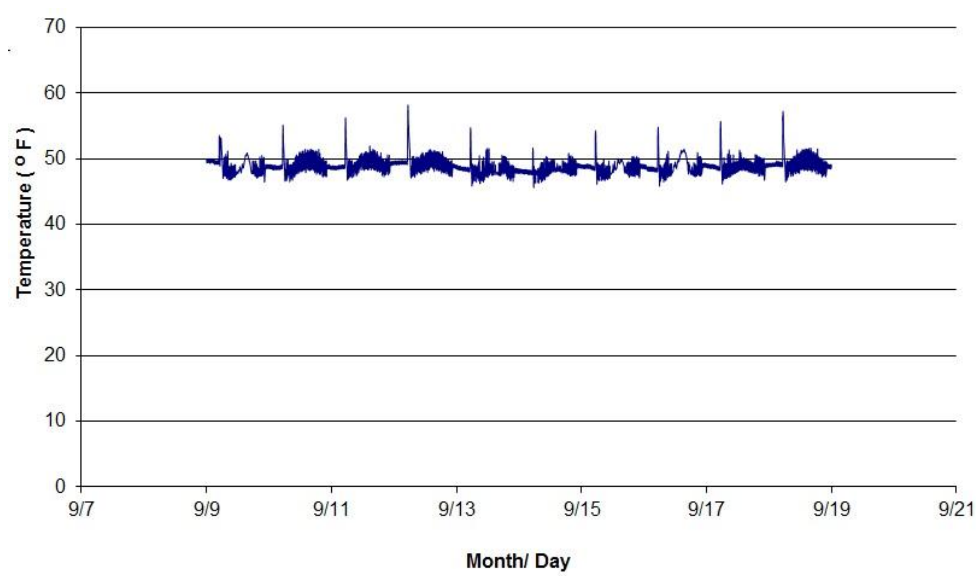


Fig. B3.2: Chiller Water Return Temperature

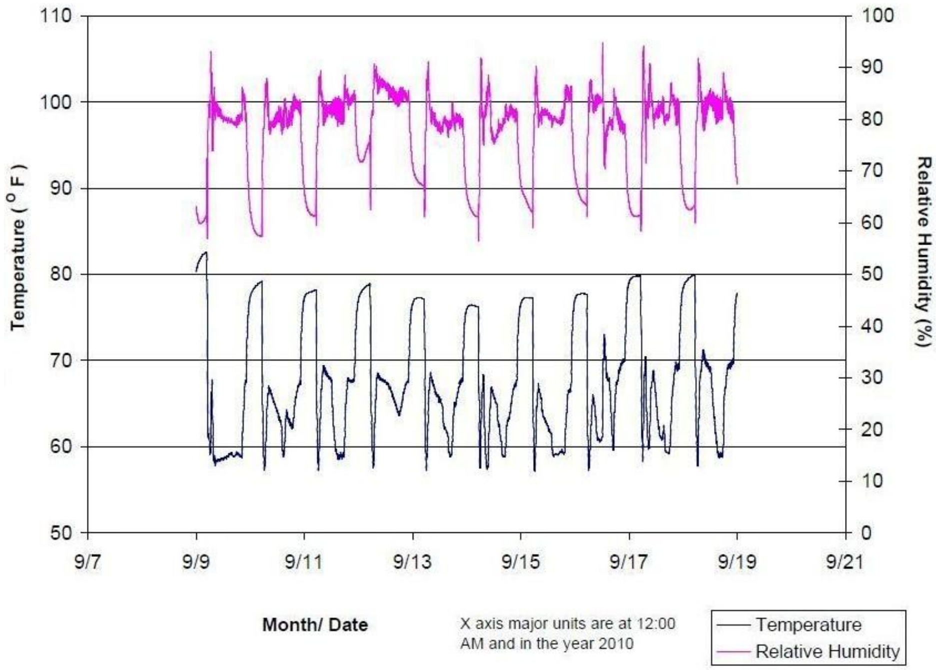


Fig. B3.3: **Dr. Snyder's Room - Supply Conditions**

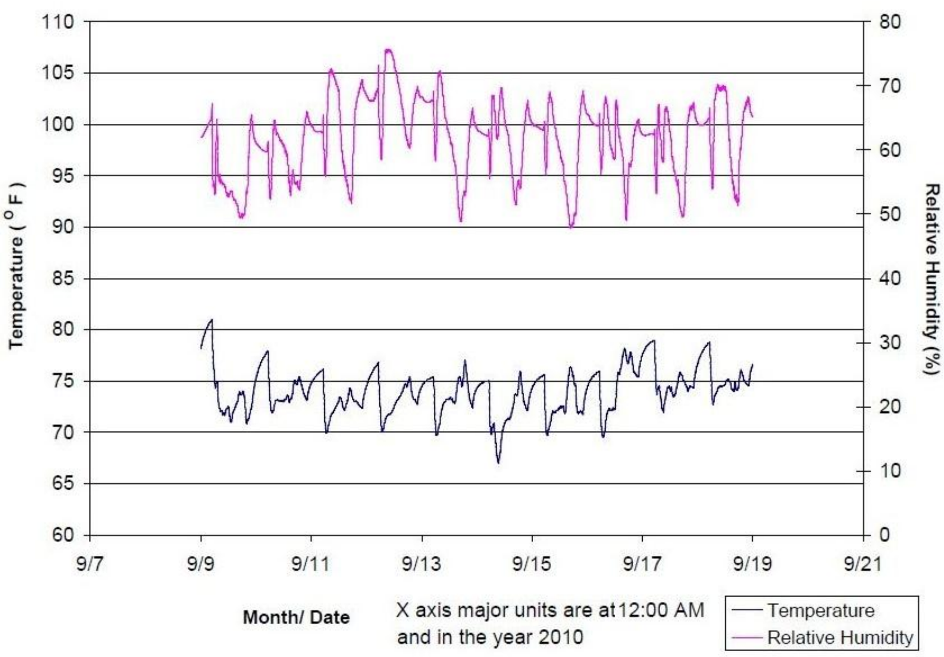


Fig. B3.4: **Dr. Snyder's Room - Room Conditions**

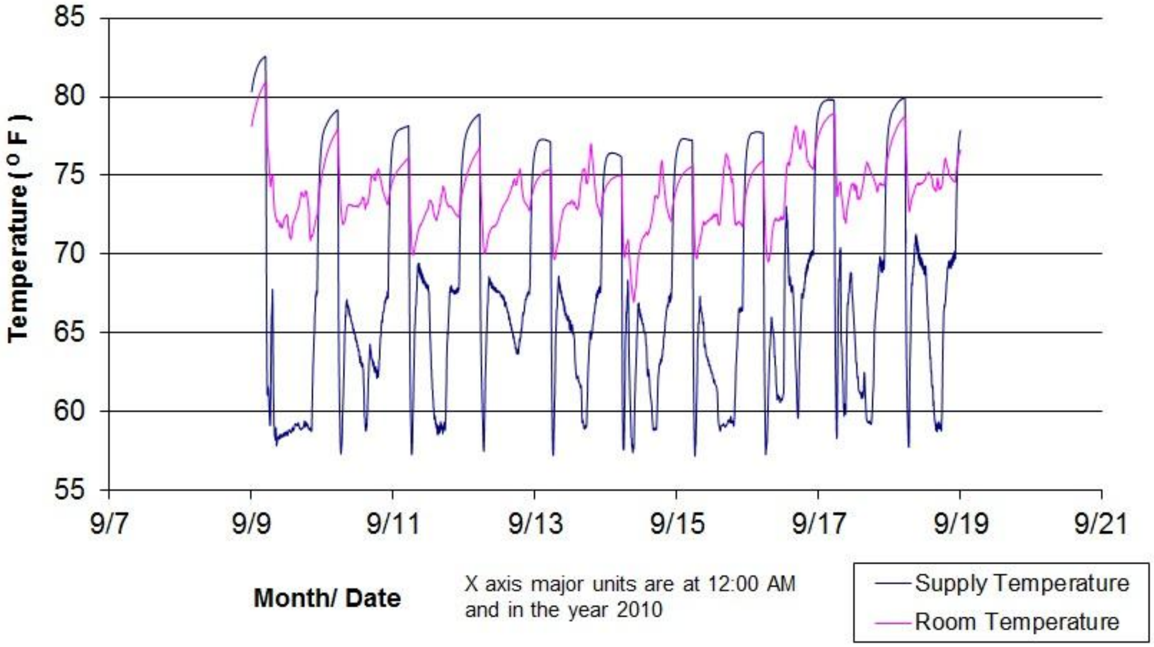


Fig. B3.5: Comparison of Supply And Room Temperatures for Dr. Snyder's Room

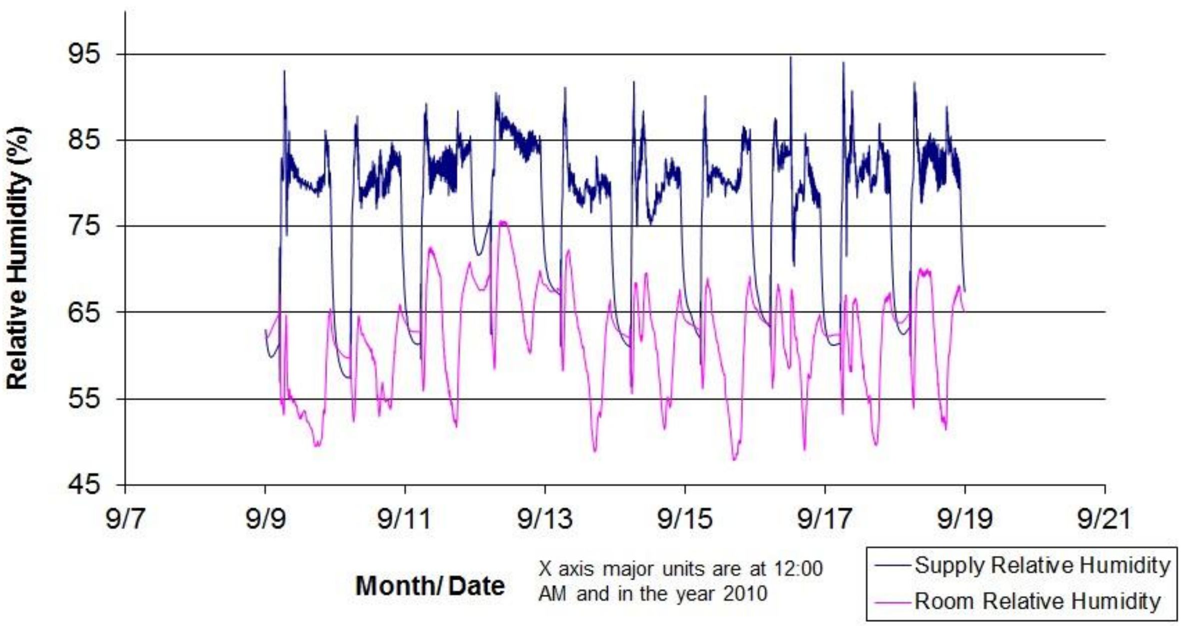


Fig. B3.6: Comparison of Supply and Room Relative Humidites for Dr.Snyder's Room

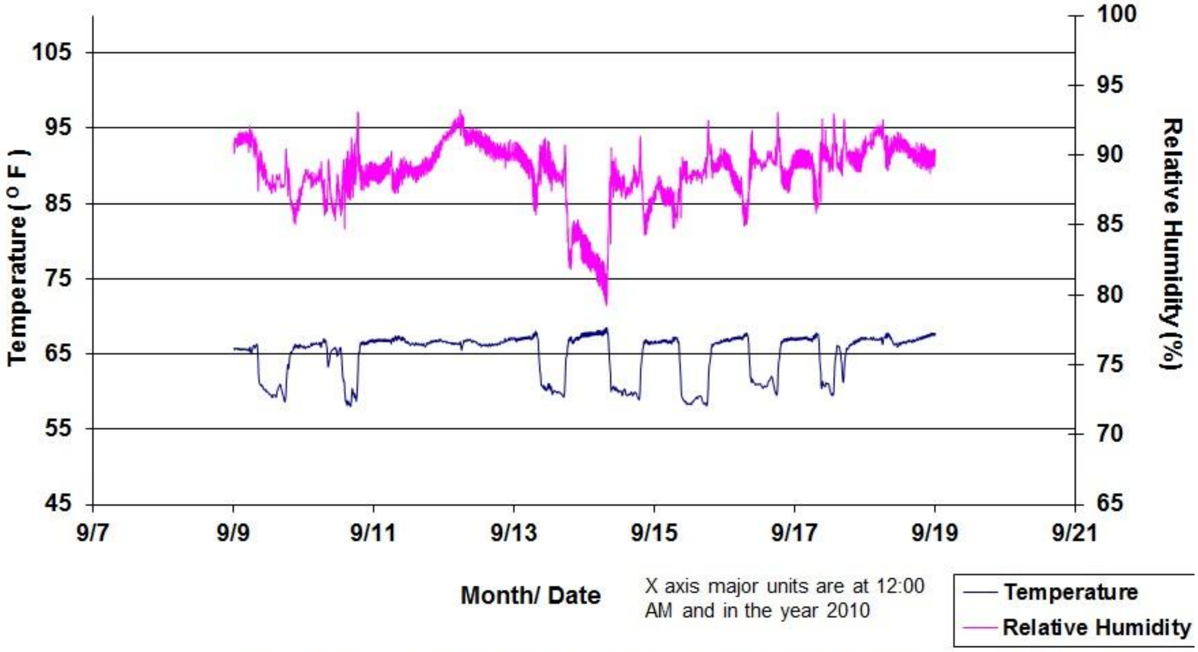


Fig. B3.7: Room 105 - Science Room - Supply Conditions

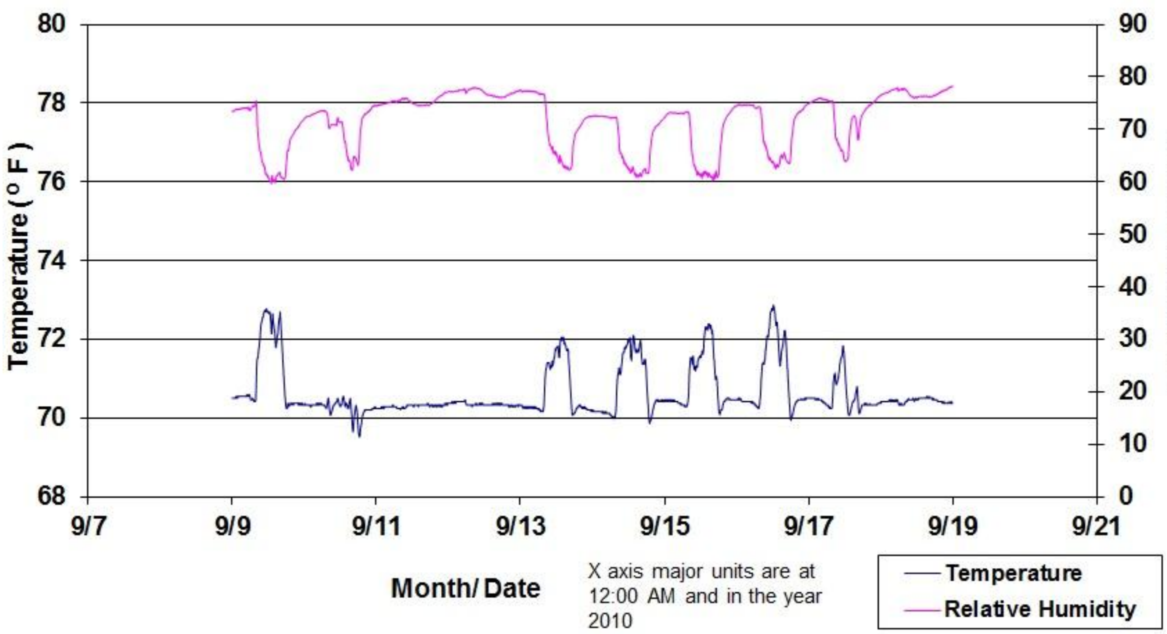


Fig. B3.8: Room 105 - Science Room - Room Conditions

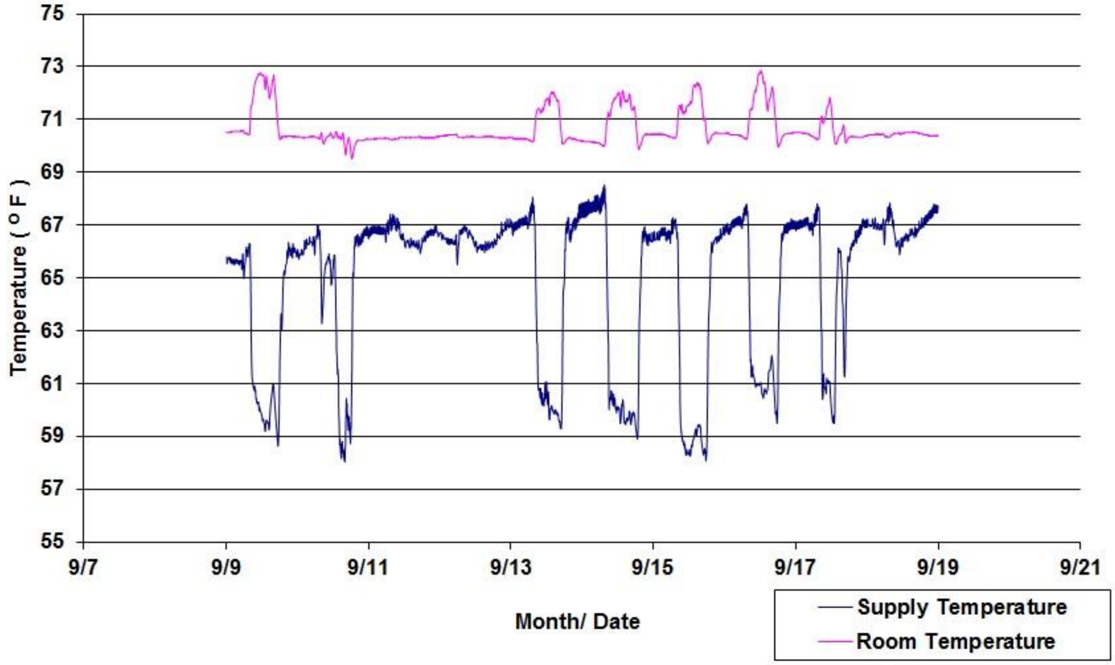


Fig. B3.9: Comparison of Supply and Room Temperatures of Room 105 - Science Room

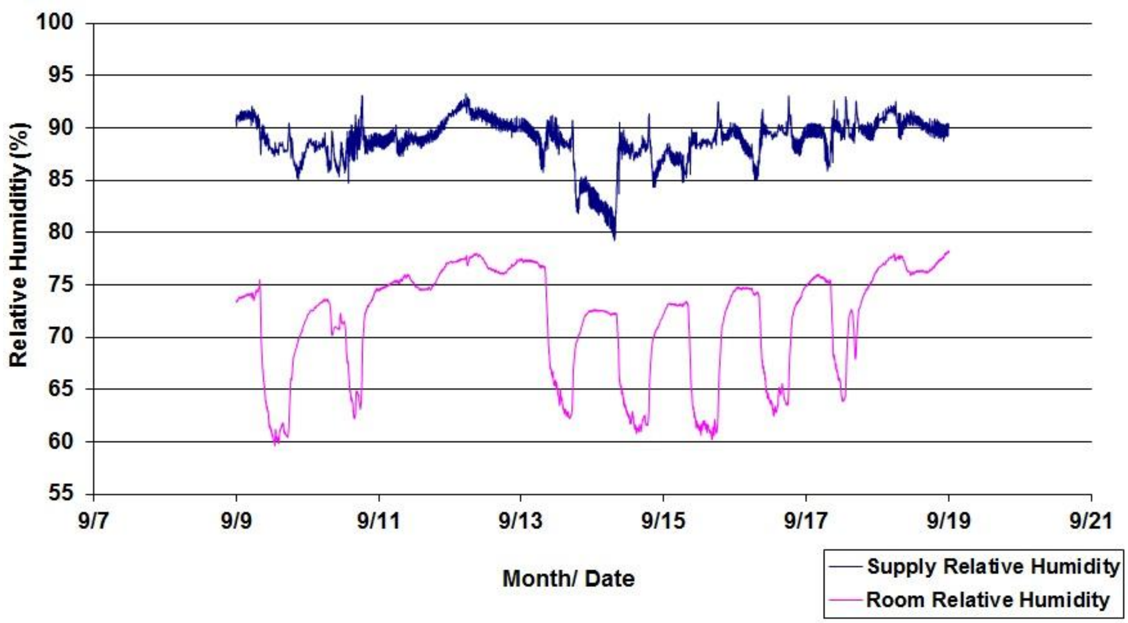


Fig. B3.10: Comparison of Supply and Room Relative Humidities in Room 105 - Science Room

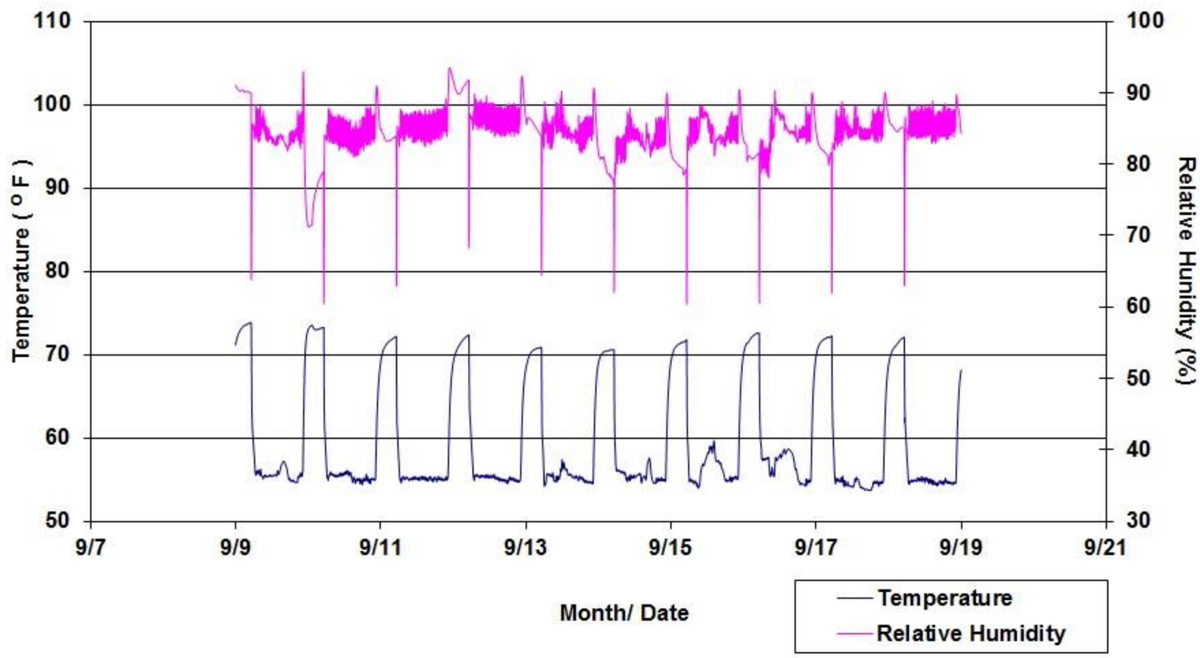


Fig. B3.11: Room 139 - Cosmetology Lab - Supply Conditions

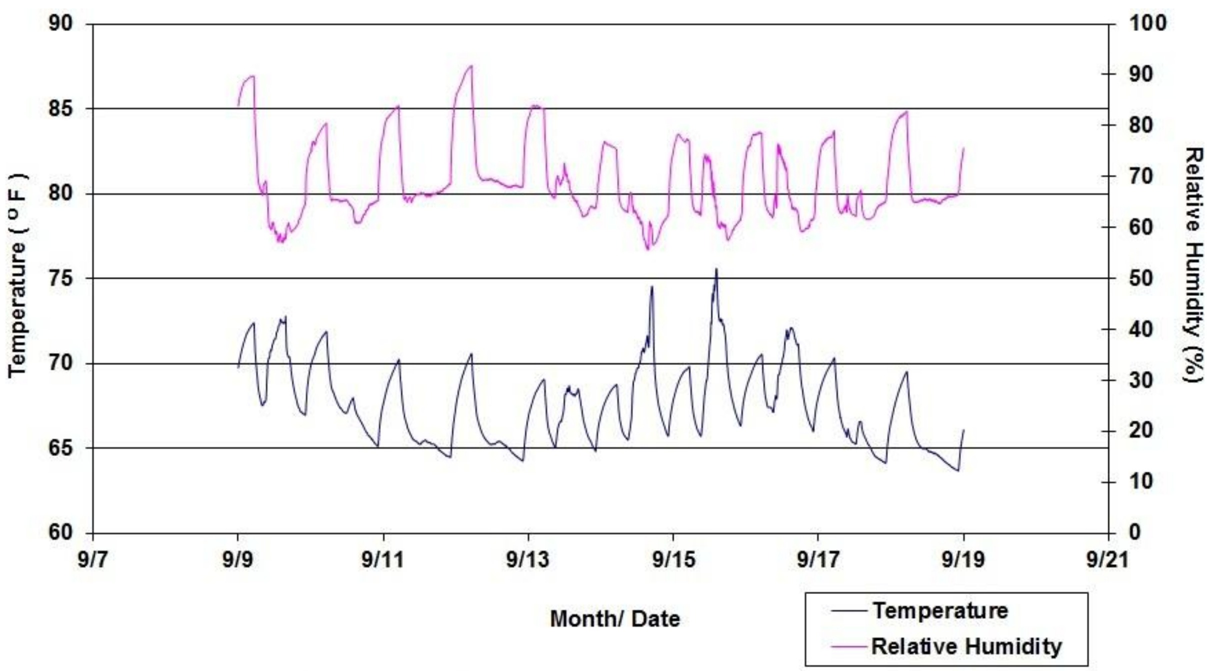


Fig. B3.12: Room 139 - Cosmetology Lab - Room Conditions

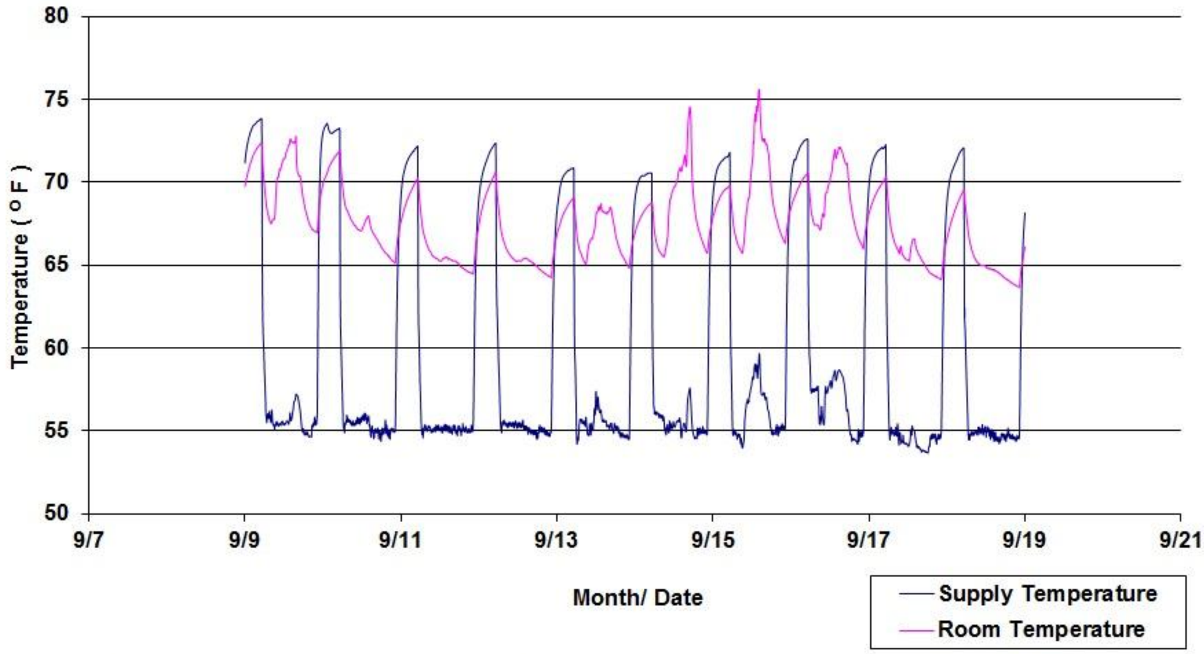


Fig. B3.13: Comparison of Supply and Room Temperatures in Room 139 - Cosmetology Lab

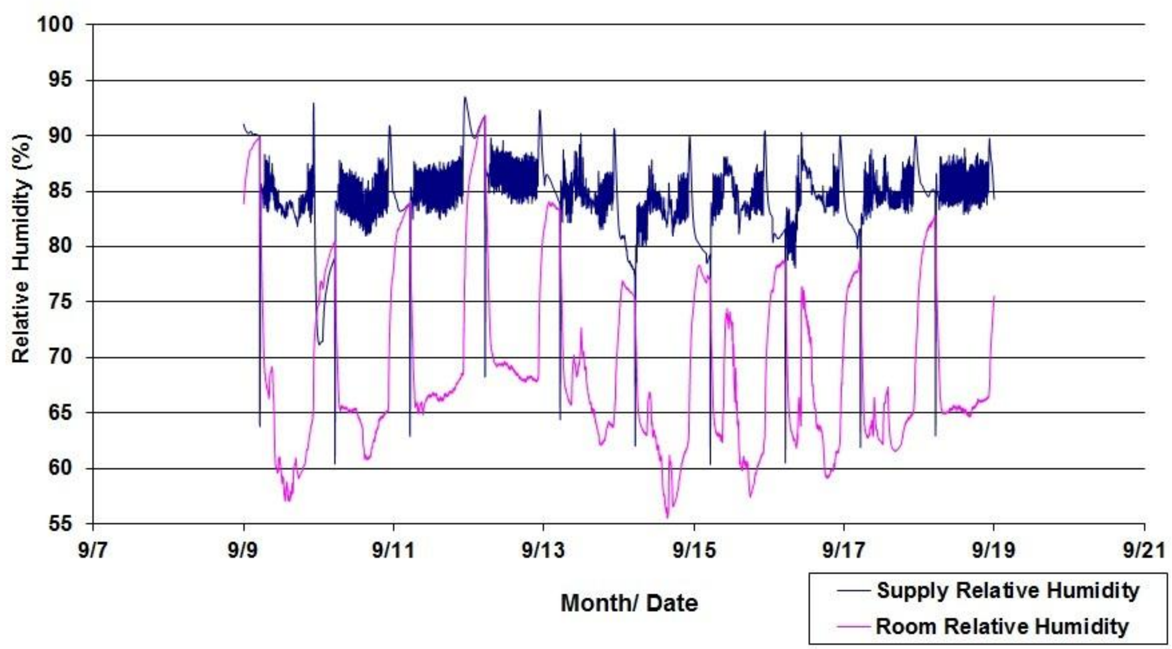


Fig. B3.14: Comparison of Supply and Room Relative Humidities in Room 139 - Cosmetology Lab

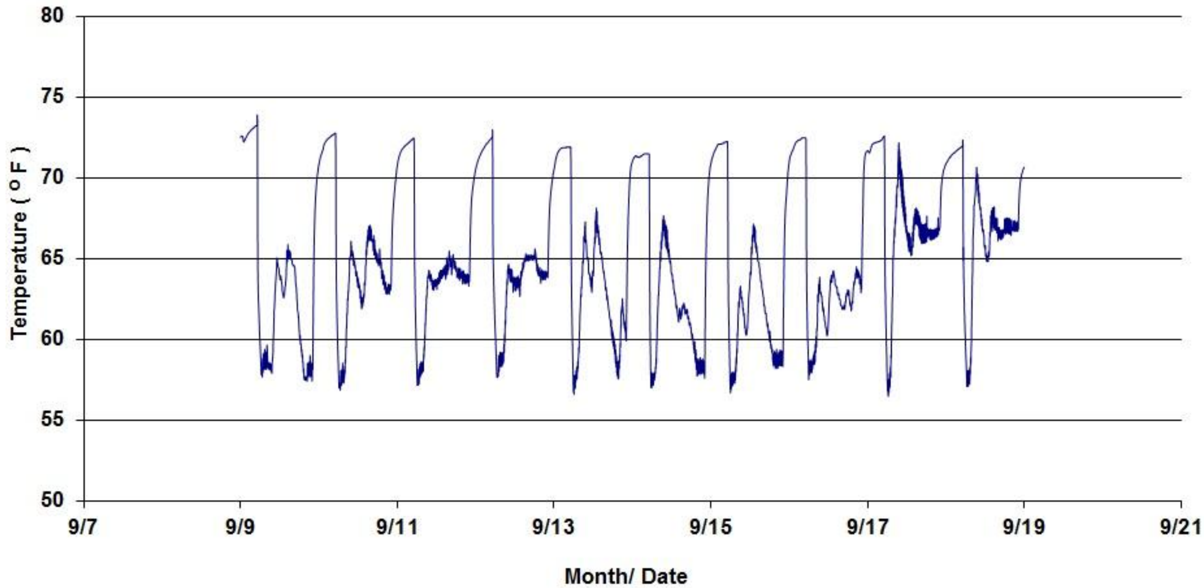


Fig. B3.15: Room 135 - Geography Room Supply Temperature

NOTE: The HOBO that was used to obtain the data above did not record Supply Air Relative Humidity.

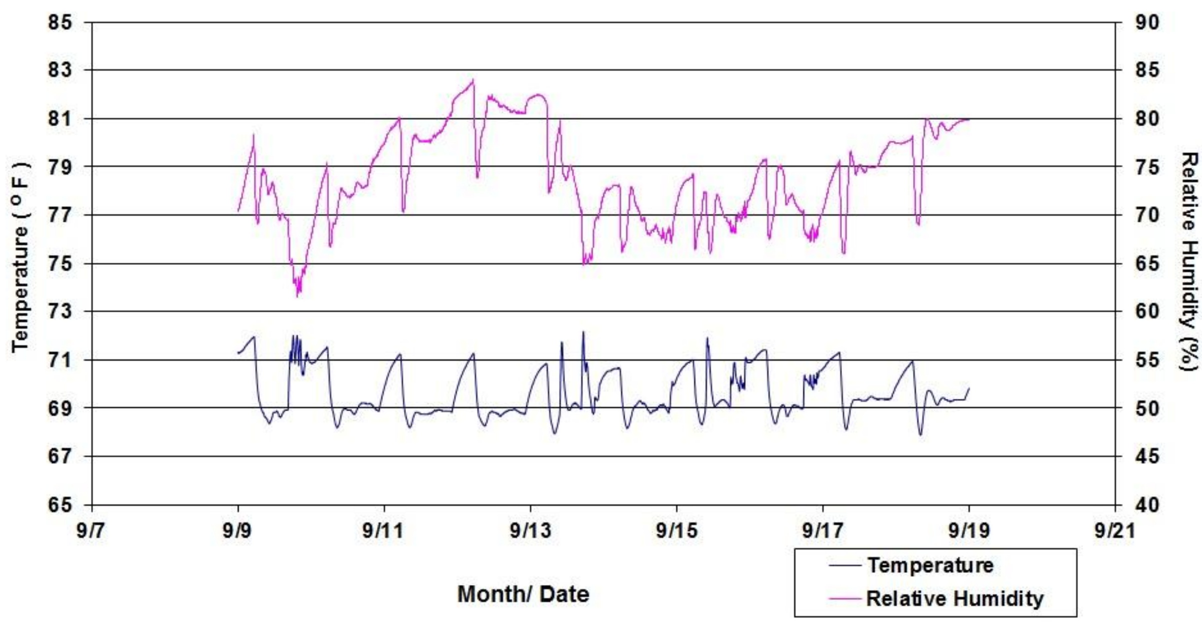


Fig. B3.16: Room 135 - Geography Room - Room Conditions

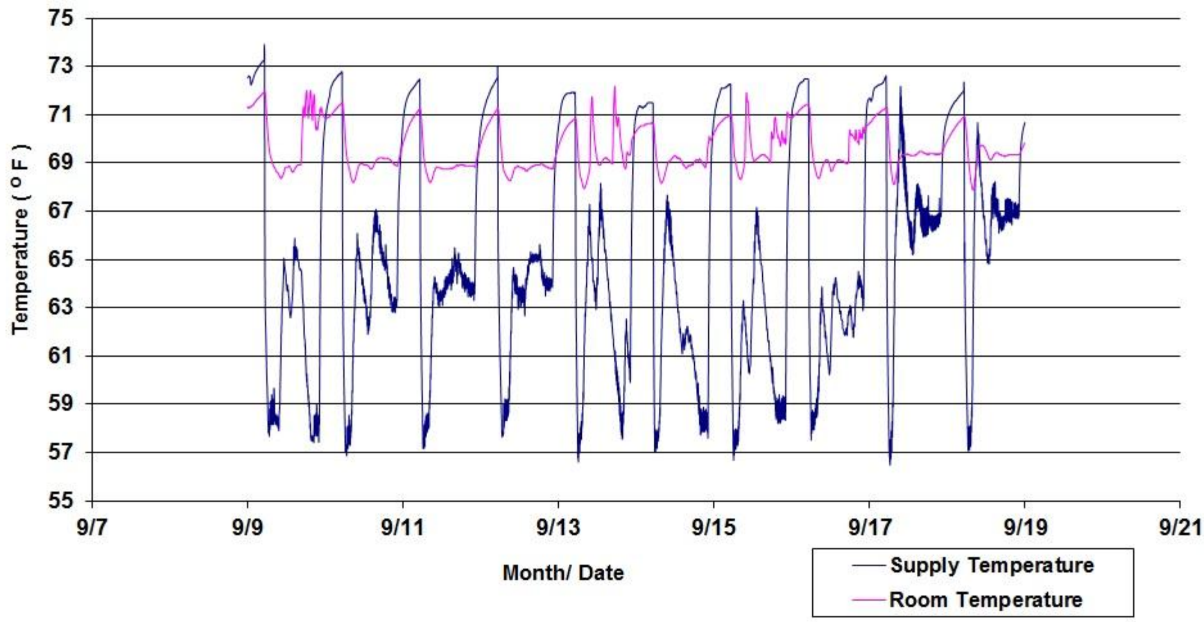


Fig. B3.17: Comparison of Supply and Room Temperatures in Room 135 - Geography Room

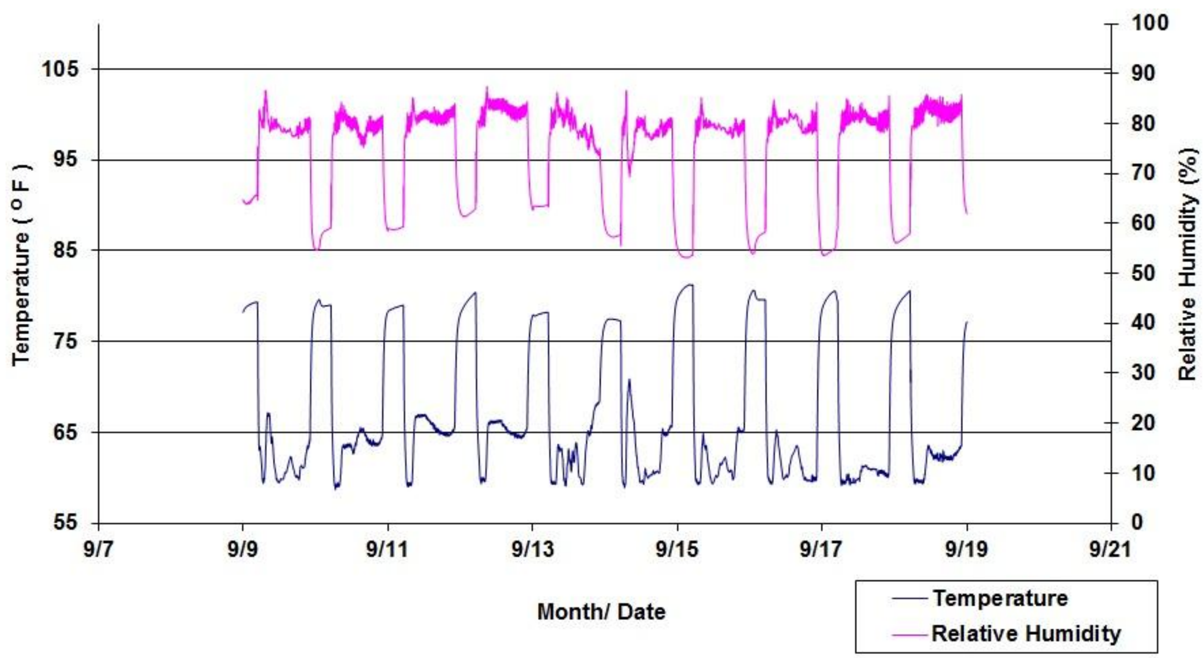


Fig. B3.18 Room 209 - Computer Room - Supply Conditions

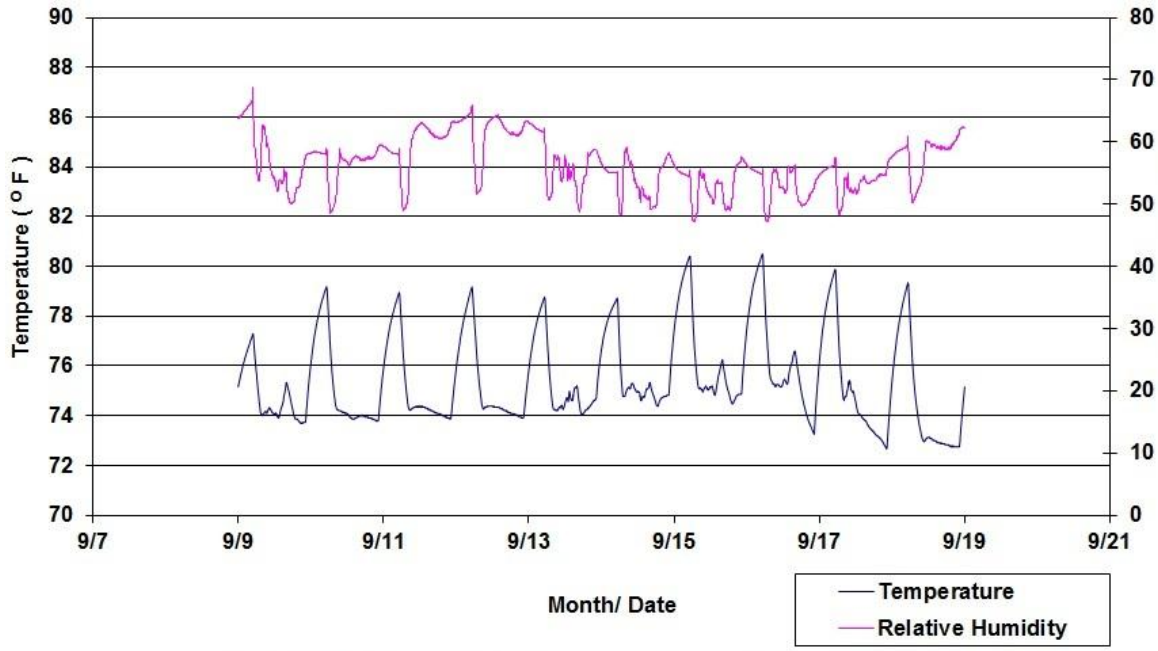


Fig. B3.19: Room 209 - Computer Room - Room Conditions

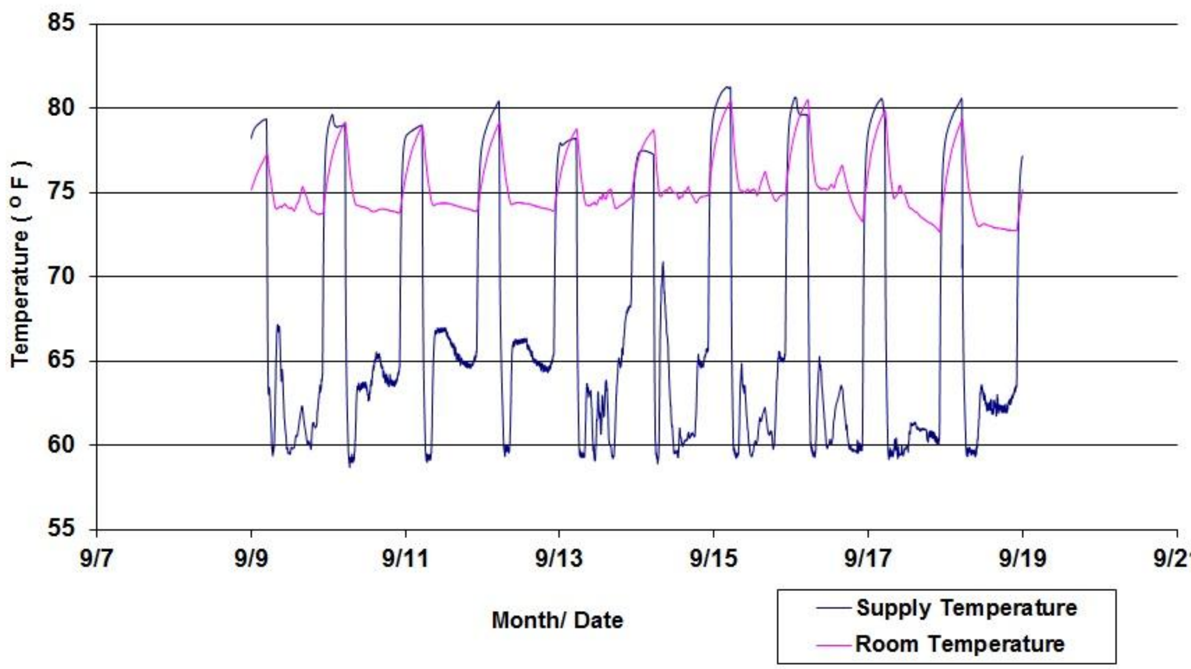


Fig. B3.20: Comparison of Supply and Room Temperatures in Room 209 - Computer Room

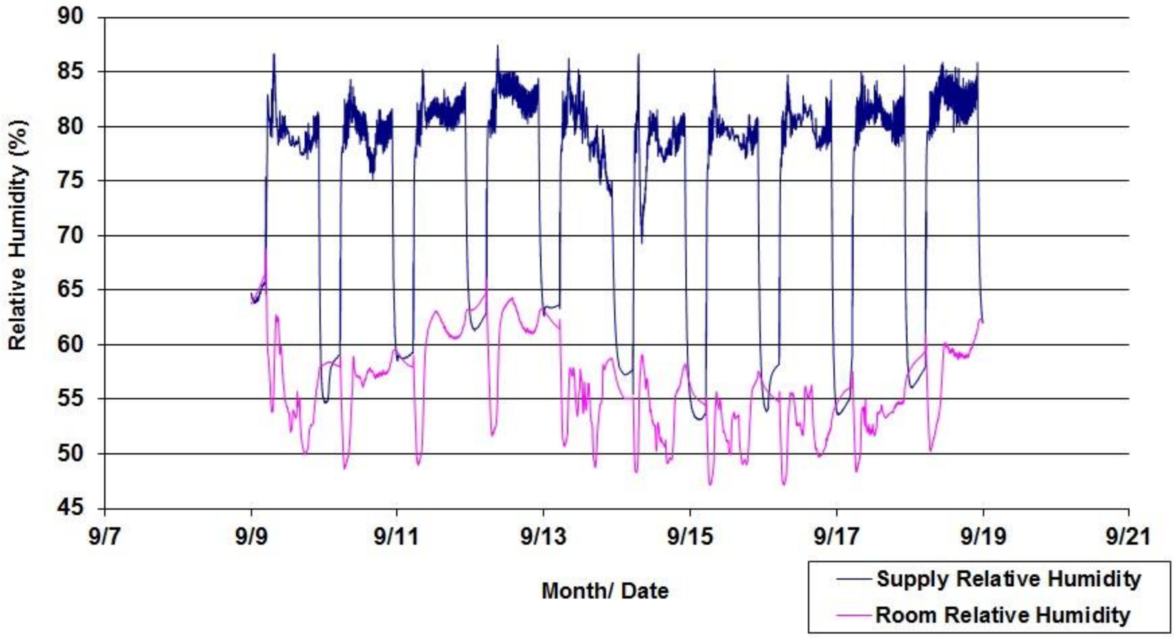


Fig. B3.21: Comparison of Supply and Room Relative Humidities in Room209 - Computer Room

APPENDIX C: INPUT DATA TO HAP 4.5

C1: Dimensions of the Building

Floor	Room No	Room	Floor Area (ft^2)	Window Area (ft^2)					Wall Area (ft^2)					Exposed Perimeter
				N	NE	E	S	W	N	NE	E	S	W	
1	140	Mechanical Equipment	533	0	0	0	52	0	0	0	0	458.25	191.75	50
1	141	Electrical Equipment	106.5	0	0	0	0	0	0	0	0	0	84.5	6.5
1	129	Classroom	883	0	0	0	52	0	0	0	0	357.5	0	27.5
1	139	Cosmetology Lab	2109	0	0	52	104	0	0	0	510.25	741	0	96.25
1	135	Waiting	289.875	0	0	9.75	0	0	0	0	32.5	0	0	2.5
1	101	Lobby 1	254	0	0	116	0	0	0	0	354.25	113.75	0	36
1	104	Classroom	493.75	0	0	52	0	0	0	0	273	185.25	0	35.25
1	105	Multi Purpose Science Lab	994.75	0	0	0	0	0	451.75	0	390	0	0	64.75
1	106	Preparation Lab	298.6875	0	0	0	0	0	266.5	0	0	0	0	20.5
1	113	Nursing Lab	890.625	0	0	0	0	0	412.75	0	0	0	0	31.75
1	116	Classroom	491.625	0	0	0	0	0	240.5	0	0	0	45.5	22
1	117	Lobby 2	391.28125	0	0	0	0	0	432.25	52	0	0	126.75	47
1	119	Women's Toilet	240.5	0	0	0	0	0	0	0	0	0	143	11
1	120	Men's Toilet	250.3125	0	0	0	0	0	0	0	0	0	178.75	13.75
1	123	Classroom	462.5	0	0	0	0	52	0	0	0	0	299	23
1	126	Classroom	558.1875	0	0	0	0	52	0	0	0	0	308.75	23.75
1	128	Classroom	655	0	0	0	0	0	0	0	0	0	237.25	18.25
1	-	Passage 1	121	0	0	0	0	0	0	0	0	0	0	0
1	127	Department Head	120	0	0	0	0	0	0	0	0	0	0	0
1	-	Elevator	41.6875	0	0	0	0	0	0	0	0	0	0	0
1	124	Mech. Room	40.25	0	0	0	0	0	0	0	0	0	0	0
1	131	Dispensary	405	0	0	0	0	0	0	0	0	0	0	0
1	134	Manicure	91	0	0	0	0	0	0	0	0	0	0	0
1	133	Office	126	0	0	0	0	0	0	0	0	0	0	0
1	132	Electrology	302.5	0	0	0	0	0	0	0	0	0	0	0
1	138	Ladies Toilet	35	0	0	0	0	0	0	0	0	0	0	0
1	137	Mens Toilet	35	0	0	0	0	0	0	0	0	0	0	0
1	115	Classroom	560	0	0	0	0	0	0	0	0	0	0	0
1	114	Mechanical Equipment	210	0	0	0	0	0	0	0	0	0	0	0

C1 Contd.

1	114A	Electrical Equipment	24	0	0	0	0	0	0	0	0	0	0	0
1	110	Department Head	117	0	0	0	0	0	0	0	0	0	0	0
1	109	Secretary	78	0	0	0	0	0	0	0	0	0	0	0
1	111	Conference Room	117	0	0	0	0	0	0	0	0	0	0	0
1	108	Office	78	0	0	0	0	0	0	0	0	0	0	0
1	112	Storage	135	0	0	0	0	0	0	0	0	0	0	0
1	107	Storage	135	0	0	0	0	0	0	0	0	0	0	0
1	103	Corridor (AHU 6)	805.625	0	0	0	0	0	0	0	0	0	0	0
1	103	Corridor (AHU 7)	733.75	0	0	0	0	0	0	0	0	0	0	0
1	103	Corridor (AHU 8)	230	0	0	0	0	0	0	0	0	0	0	0
1	122	Toilet	33.75	0	0	0	0	0	0	0	0	0	0	0
1	121	Jan. Closet	35.4375	0	0	0	0	0	0	0	0	0	0	0
2	236	Typing Lab	917.5	0	0	0	52	104	0	0	0	328.25	510.25	64.5
2	238	Storage Room	117	0	0	0	0	0	0	0	0	130	0	10
2	239	Typing Room	907	0	0	0	52	0	0	0	0	318.5	0	24.5
2	241	Computer Lab	917.625	0	0	0	52	0	0	0	0	318.5	0	24.5
2	245	Storage Room	92.5	0	0	0	0	0	0	0	0	136.5	0	10.5
2	244	Computer Lab	912	0	0	52	52	0	0	0	510.25	328.25	0	64.5
2	247	Classroom	346.5	0	0	9.75	0	0	0	0	32.5	0	0	2.5
2	-	Lobby 1 (Upstairs)	224.25	0	0	0	0	0	0	0	354.25	113.75	0	36
2	202	Classroom	503.625	0	0	52	0	0	0	0	273	182	0	35
2	203	Classroom	726.75	52	0	52	0	0	351	0	390	0	0	57
2	204	Classroom	498	52	0	0	0	0	276.25	0	0	0	0	21.25
2	205	Classroom	689.5625	52	0	0	0	0	315.25	0	0	0	0	24.25
2	219	Faculty Longue	236.25	52	0	0	0	0	295.75	0	0	0	0	22.75
2	218	Department Head	117	0	0	0	0	0	130	0	0	0	0	10
2	-	Lobby 2 Upstairs	423.8125	101.25	0	0	0	0	487.5	0	0	0	126.75	47.25
2	222	Women's Toilet	261.15625	0	0	0	0	0	0	0	0	0	152.75	11.75
2	223	Men's Toilet	225.625	0	0	0	0	0	0	0	0	0	165.75	12.75
2	226	Double Office	156.75	0	0	0	0	0	0	0	0	0	126.75	9.75
2	229	Department Head	112.5	0	0	0	0	52	0	0	0	0	152.75	11.75

C1 Contd.

2	230	Secretary	346.5	0	0	0	0	52	0	0	0	0	195	15
2	233	Office	78.375	0	0	0	0	0	0	0	0	0	130	10
2	237	Work Room	195	0	0	0	0	0	0	0	0	0	0	0
2	243	Office	120	0	0	0	0	0	0	0	0	0	0	0
2	242	Storage Room	160	0	0	0	0	0	0	0	0	0	0	0
2	234	Office	78.375	0	0	0	0	0	0	0	0	0	0	0
2	235	Office	78.375	0	0	0	0	0	0	0	0	0	0	0
2	231	Copy Room	61.75	0	0	0	0	0	0	0	0	0	0	0
2	228	Elect. Equip	26	0	0	0	0	0	0	0	0	0	0	0
2	-	Elevator	39.875	0	0	0	0	0	0	0	0	0	0	0
2	225	Office	78.625	0	0	0	0	0	0	0	0	0	0	0
2	224	Mechanical Equipment & Janitorial	69.1875	0	0	0	0	0	0	0	0	0	0	0
2	246	Classroom	432	0	0	0	0	0	0	0	0	0	0	0
2	240	Mechanical Equipment	258.75	0	0	0	0	0	0	0	0	0	0	0
2	206	Classroom	508.5625	0	0	0	0	0	0	0	0	0	0	0
2	208	Mechanical Equipment	124	0	0	0	0	0	0	0	0	0	0	0
2	208A	Electrical Room	18	0	0	0	0	0	0	0	0	0	0	0
2	212	Double Office	134	0	0	0	0	0	0	0	0	0	0	0
2	211	Double Office	134	0	0	0	0	0	0	0	0	0	0	0
2	210	Double Office	134	0	0	0	0	0	0	0	0	0	0	0
2	213	Office	64	0	0	0	0	0	0	0	0	0	0	0
2	214	Office	64	0	0	0	0	0	0	0	0	0	0	0
2	215	Office	64	0	0	0	0	0	0	0	0	0	0	0
2	217	Office	64	0	0	0	0	0	0	0	0	0	0	0
2	221	Ladies Toilet	36.25	0	0	0	0	0	0	0	0	0	0	0
2	220	Mens Toilet	36.25	0	0	0	0	0	0	0	0	0	0	0
2	216	Secretary (AHU 14)	282.375	0	0	0	0	0	0	0	0	0	0	0
2	216	Secretary (AHU 15)	89.0625	0	0	0	0	0	0	0	0	0	0	0
2	248	Passage	259.625	0	0	0	0	0	0	0	0	0	0	0
2	201	Corridor (AHU 14)	999.6875	0	0	0	0	0	0	0	0	0	0	0
2	201	Corridor (AHU 16)	249	0	0	0	0	0	0	0	0	0	0	0
2	201	Corridor (AHU 17)	741.75	0	0	0	0	0	0	0	0	0	0	0
2	201	Corridor (AHU 18)	129.6875	0	0	0	0	0	0	0	0	0	0	0

C2: Mechanical Data from Charts

AHU	AIR QUANTITY		ELECTRICAL	COOLING COIL							HEATING COIL		
	TOTAL CFM	OUTSIDE CFM	MAX H.P.	EDB (^{O}F)	EWB (^{O}F)	LDB (^{O}F)	LWB (^{O}F)	GTH - MBH	GPM	RUNOUT SIZE	GTH - MBH	GPM	RUNOUT SIZE
1	3000	2100	5	89.9	77.2	58.8	58.7	207	42	2"	140	14	1-1/2"
2	1000	100	2	79.8	66.9	56.5	55.2	35	7	1-1/4"	13	1.5	3/4"
3	1200	125	2	80.1	67.4	57.5	56.2	36	8	1-1/4"	11	1.5	3/4"
4	3725	250	5	79.3	67.2	59.5	57.9	112	23	2"	36	4	3/4"
5	650	100	3	78.3	65.5	53.6	52.5	26	6	1-1/4"	8	1	3/4"
6	2475	275	3	79.7	71.4	68.2	65.9	52	11	1-1/2"	19	2	3/4"
7	1600	125	3	79.6	66.9	59	57.4	46	10	1-1/4"	20	2	3/4"
8	1600	175	5	80	67.9	59	57.5	54	11	1-1/2"	19	2	3/4"
9	2400	150	3	79.3	66.4	61	58.7	60	12	1-1/4"	30	3	3/4"
10	1600	100	3	79.3	65.7	57.6	55.9	50	10	1-1/2"	18	2	3/4"
11	1400	125	3	79.7	67.1	58.5	57	44	9	1-1/2"	16	2	3/4"
12	1200	125	2	79.8	66.8	56.6	55.3	42	9	1-1/4"	15	1.5	3/4"
13	1800	150	3	79.6	66.2	56.7	55.3	62	13	1-1/2"	23	2.5	3/4"
14	1800	200	3	80.1	67.5	59.9	58.2	54	11	1-1/4"	20	2	3/4"
15	800	75	3	79.5	67.4	62	59.8	21	5	1"	12	1.5	3/4"
16	2000	155	5	79.4	66.7	57.8	56.4	64	13	1-1/2"	26	3	3/4"
17	1800	175	2	79.6	67.9	58.8	57.4	62	13	1-1/4"	17	2	3/4"
18	1800	150	3	79.6	67.1	57.3	56.1	64	13	1-1/4"	20	2	3/4"

C3: Electrical Plan Data showing Maximum Electrical Equipment Wattage in each space

Floor	Room No	Room	Watts	Floor	Room No	Room	Watts	Floor	Room No	Room	Watts
1	140	Mechanical Equipment	0	1	109	Secretary	540	2	237	Work Room	720
1	141	Electrical Equipment	0	1	111	Conference Room	540	2	243	Office	540
1	129	Classroom	3900	1	108	Office	540	2	242	Storage Room	180
1	139	Cosmetology Lab	117000	1	112	Storage	180	2	234	Office	180
1	135	Waiting	720	1	107	Storage	180	2	235	Office	180
1	101	Lobby 1	1080	1	103	Corridor (AHU 6)	180	2	231	Copy Room	360
1	104	Classroom	900	1	103	Corridor (AHU 7)	1380	2	228	Elect. Equip	0
1	105	Multi Purpose Science Lab	7140	1	103	Corridor (AHU 8)	1380	2	-	Elevator	0
1	106	Preparation Lab	9080	1	122	Toilet	0	2	225	Office	360
1	113	Nursing Lab	1720	1	121	Jan. Closet	180	2	224	Mechanical Equipment & Janitorial	0
1	116	Classroom	720	2	236	Typing Lab	5940	2	246	Classroom	750
1	117	Lobby 2	780	2	238	Storage Room	180	2	240	Mechanical Equipment	180
1	119	Women's Toilet	2580	2	239	Typing Room	5940	2	206	Classroom	750
1	120	Men's Toilet	2580	2	241	Computer Lab	5940	2	208	Mechanical Equipment	180
1	123	Classroom	900	2	245	Storage Room	180	2	208A	Electrical Room	0
1	126	Classroom	823	2	244	Computer Lab	10440	2	212	Double Office	522
1	128	Classroom	900	2	247	Classroom	900	2	211	Double Office	522
1	-	Passage 1	180	2	-	Lobby 1 (Upstairs)	154	2	210	Double Office	522
1	127	Department Head	617	2	202	Classroom	771	2	213	Office	315
1	-	Elevator	0	2	203	Classroom	900	2	214	Office	315
1	124	Mech. Room	0	2	204	Classroom	900	2	215	Office	315
1	131	Dispensary	360	2	205	Classroom	1260	2	217	Office	324
1	134	Manicure	540	2	219	Faculty Longue	4686	2	221	Ladies Toilet	2580
1	133	Office	540	2	218	Department Head	540	2	220	Mens Toilet	2580
1	132	Electrology	2670	2	-	Lobby 2 Upstairs	180	2	216	Secretary (AHU 14)	517.5
1	138	Ladies Toilet	180	2	222	Women's Toilet	2580	2	216	Secretary (AHU 15)	162
1	137	Mens Toilet	180	2	223	Men's Toilet	2580	2	248	Passage	180
1	115	Classroom	900	2	226	Double Office	540	2	201	Corridor (AHU 14)	499.5
1	114	Mechanical Equipment	0	2	229	Department Head	540	2	201	Corridor (AHU 16)	150
1	114A	Electrical Equipment	0	2	230	Secretary	720	2	201	Corridor (AHU 17)	1350
1	110	Department Head	540	2	233	Office	360	2	201	Corridor (AHU 18)	180

C4: Lighting Fixture Schedule

Lighting Fixture Schedule				
Type	Lamp	Description	Mounting	Remarks
A	(4) F40T12RS	2' X 4' Fluorescent	Recessed	
B	(3) F40T12RS	2' X 4' Fluorescent	Recessed	
C	(2) F40T12RS	2' X 4' Fluorescent	Recessed	
D	(2) F40T12U	2' X 2' Fluorescent	Recessed	
E	(2) F40T12RS	6' X 4' Perimeter Fluorescent	Recessed	
F	(2) F40T12RS	4' Fluorescent Bracket	Wall	
G	(2) F40T12RS	4' Industrial Fluorescent	Ceiling	Coordinate W/ Mech
H	(2) F40T12RS	4' Fluorescent Bracket	Wall	
I	(2) F40T12RS	6" X 20' Fluorescent Tube	Suspended	120 V Ballast
J	(1) F40T12RS	4' Fluorescent Strip	Above Door	
K	(1) 150 W A - 21	Incandescent Downlight	Recessed	
L	(1) 175 W MH	H.I.D. Downlight	Recessed	U.L. Damp Label
M	(6) 75 W R30	One Circuit Light Track	Surface	
N	(1) 100 W A - 21	Vapor Tight Incandescent Bracket	Wall	W/ Globe & Guard
P	(1) 40 W G	Broadway Lighting Channel	Wall	1 Lamp Per 12"
XA	(1) 12 W Tungsten Halogen	Battery Operated Emergency Light	Recessed	
X	(2) 20 W T 6 1/2'	Battery Operated Exit Light	As Indicated	Universal Mounting
AA	(1) 400 W HPS	Pole Mounted Area Light	30' Pole	Type V (Square) Dist.
BB	(1) 150 W HPS	Pole Mounted Area Light	15' Pole	Type I Distribution

C5: Lighting Fixtures and Maximum Wattage in each space

Floor	Room No	Room	Lighting Fixture Types - Number of Such Fixtures	Total Lighting Wattage in Room
1	140	Mechanical Equipment	G - 7 ; XA - 2	654
1	141	Electrical Equipment	G - 3 ; XA - 1	282
1	129	Classroom	B - 15 ; D - 1	2190
1	139	Cosmetology Lab	B - 28, X - 1	3960
1	135	Waiting	B - 1 ; C - 1 ; E - 3	500
1	101	Lobby 1	K - 6 ; XA - 1 ; H - 1	1002
1	104	Classroom	B - 9	1260
1	105	Multi Purpose Science Lab	A - 17	3060
1	106	Preparation Lab	B - 4	560
1	113	Nursing Lab	B - 13 ; D - 4	2180
1	116	Classroom	B - 8	1120
1	117	Lobby 2	K - 4 ; XA - 2 ; H - 1	714
1	119	Women's Toilet	C - 3 ; F - 2	450
1	120	Men's Toilet	C - 5 ; F - 2	630
1	123	Classroom	B - 10	1400
1	126	Classroom	B - 9	1260
1	128	Classroom	B - 13	1820
1	-	Passage 1	C - 2 ; X - 1	490
1	127	Department Head	C - 4	360
1	-	Elevator	-	0
1	124	Mech. Room	G - 1	90
1	131	Dispensary	C - 6	540
1	134	Manicure	B - 2	280
1	133	Office	C - 4	360
1	132	Electrology	B - 6	840
1	138	Ladies Toilet	F - 1	90
1	137	Mens Toilet	F - 1	90
1	115	Classroom	B - 9	1260
1	114	Mechanical Equipment	G - 2 ; XA - 1	192

C5 Contd.

1	114A	Electrical Equipment	J - 1	50
1	110	Department Head	C - 4	360
1	109	Secretary	B - 2	280
1	111	Conference Room	C - 4	360
1	108	Office	B - 2	280
1	112	Storage	C - 2	180
1	107	Storage	C - 2	180
1	103	Corridor (AHU 6)	C - 7 ; XA - 3 ; X - 2	746
1	103	Corridor (AHU 7)	C - 9 ; XA - 2 ; X - 1	914
1	103	Corridor (AHU 8)	C - 3 ; XA - 2 ; X - 1	334
1	122	Toilet	C - 1	90
1	121	Jan. Closet	C - 1	90
2	236	Typing Lab	B - 12	1680
2	238	Storage Room	C -2	180
2	239	Typing Room	B - 12	1680
2	241	Computer Lab	B - 12	1680
2	245	Storage Room	C -1	90
2	244	Computer Lab	I - 6	540
2	247	Classroom	B - 9	1260
2	-	Lobby 1 (Upstairs)	H - 2 ; XA - 1 ; C - 1	282
2	202	Classroom	B - 9	1260
2	203	Classroom	B - 12	1680
2	204	Classroom	B - 9	1260
2	205	Classroom	B - 12	1680
2	219	Faculty Longue	K - 6	900
2	218	Department Head	C - 4	360
2	-	Lobby 2 Upstairs	C - 2 ; XA - 2 ; H - 2 ; X - 1	424
2	222	Women's Toilet	C - 3 ; F - 2	450
2	223	Men's Toilet	C - 3 ; F - 2	450
2	226	Double Office	B - 3	420
2	229	Department Head	C - 4	360

C5 Contd.

2	230	Secretary	C - 3 ; B - 4	830
2	233	Office	B - 2	280
2	237	Work Room	B - 3	420
2	243	Office	C - 4	360
2	242	Storage Room	C - 2	180
2	234	Office	B - 2	280
2	235	Office	B - 2	280
2	231	Copy Room	C - 2	180
2	228	Elect. Equip	G -1	90
2	-	Elevator	-	0
2	225	Office	B - 2	280
2	224	Mechanical Equipment & Janitorial	G - 1	90
2	246	Classroom	B - 9	1260
2	240	Mechanical Equipment	G - 2 ; XA - 1	192
2	206	Classroom	B - 9	1260
2	208	Mechanical Equipment	G - 2 ; XA - 1	192
2	208A	Electrical Room	J - 1	50
2	212	Double Office	B - 3	420
2	211	Double Office	B - 3	420
2	210	Double Office	B - 3	420
2	213	Office	B - 2	280
2	214	Office	B - 2	280
2	215	Office	B - 2	280
2	217	Office	B - 2	280
2	221	Ladies Toilet	F - 1	90
2	220	Mens Toilet	F - 1	90
2	216	Secretary (AHU 14)	C - 3 ; B - 2 ; XA - 2	574
2	216	Secretary (AHU 15)	K - 2	300
2	248	Passage	C - 4	360
2	201	Corridor (AHU 14)	C - 9 ; XA - 4 ; X - 2	938
2	201	Corridor (AHU 16)	C - 3 ; XA - 1 ; X - 1	322
2	201	Corridor (AHU 17)	C - 8 ; XA - 2 ; X - 1	784
2	201	Corridor (AHU 18)	C - 1 ; XA - 1	102

C6: Data Provided by Palmetto Air & Water Balance

System	Actual Supply Air CFM	Actual Return Air CFM	Actual Outside Air CFM	Actual Exhaust Air CFM
AHU 1	2,202	2,147	55	
AHU 2	931	N/M	15	
AHU 3	1,372	1,300	72	
AHU 4	3,000	2,963	37	
AHU 5	795	707	88	
AHU 6	2,529	2,218	311	
AHU 7	1,488	1,445	43	
AHU 8	1,658	747	911	
AHU 9	N/M	N/M	30	
AHU 10	N/M	N/M	128	
AHU 11	N/M	N/M	107	
AHU 12	N/M	N/M	64	
AHU 13	1,558	1,542	16	
AHU 14	1,685	1,545	140	
AHU 15	N/M	N/M	79	
AHU 16	N/M	N/M	115	
AHU 17	N/M	N/M	123	
AHU 18	N/M	N/M	255	
EF 3				1,296
EF 4				NOT OPERATIONAL
EF 5				255
EF 6				101
EF 7				NOT OPERATIONAL

NOTE 1: N/M refers to Not Measured and EF refers to Exhaust Fans.

NOTE 2: By performing this testing, Palmetto Air & Water Balance claimed that they achieved a positive pressure of 0.0008” of water.

C7: Assumption on Maximum Occupancy of spaces in Building 'C'

Room No	Room	Maximum Occupancy	Room No	Room	Maximum Occupancy	Room No	Room	Maximum Occupancy
140	Mechanical Equipment	5	109	Secretary	1	237	Work Room	6
141	Electrical Equipment	1	111	Conference Room	15	243	Office	3
129	Classroom	33	108	Office	1	242	Storage Room	0
139	Cosmetology Lab	37	112	Storage	0	234	Office	1
135	Waiting	10	107	Storage	0	235	Office	1
101	Lobby 1	15	103	Corridor (AHU 6)	20	231	Copy Room	1
104	Classroom	33	103	Corridor (AHU 7)	20	228	Elect. Equip	1
105	Multi Purpose Science Lab	36	103	Corridor (AHU 8)	20	-	Elevator	0
106	Preparation Lab	12	122	Toilet	1	225	Office	1
113	Nursing Lab	36	121	Jan. Closet	0	224	Mechanical Equipment & Janitorial	0
116	Classroom	33	236	Typing Lab	33	246	Classroom	33
117	Lobby 2	15	238	Storage Room	0	240	Mechanical Equipment	1
119	Women's Toilet	10	239	Typing Room	33	206	Classroom	33
120	Men's Toilet	10	241	Computer Lab	33	208	Mechanical Equipment	1
123	Classroom	33	245	Storage Room	0	208A	Electrical Room	1
126	Classroom	33	244	Computer Lab	33	212	Double Office	3
128	Classroom	33	247	Classroom	33	211	Double Office	3
-	Passage 1	7	-	Lobby 1 (Upstairs)	15	210	Double Office	3
127	Department Head	1	202	Classroom	33	213	Office	1
-	Elevator	0	203	Classroom	33	214	Office	1
124	Mech. Room	1	204	Classroom	33	215	Office	1
131	Dispensary	10	205	Classroom	33	217	Office	1
134	Manicure	10	219	Faculty Longue	15	221	Ladies Toilet	1
133	Office	3	218	Department Head	1	220	Mens Toilet	1
132	Electrology	10	-	Lobby 2 Upstairs	15	216	Secretary (AHU 14)	5
138	Ladies Toilet	1	222	Women's Toilet	10	216	Secretary (AHU 15)	2
137	Mens Toilet	1	223	Men's Toilet	10	248	Passage	7
115	Classroom	33	226	Double Office	4	201	Corridor (AHU 14)	20
114	Mechanical Equipment	1	229	Department Head	1	201	Corridor (AHU 16)	150
114A	Electrical Equipment	1	230	Secretary	5	201	Corridor (AHU 17)	20
110	Department Head	1	233	Office	1	201	Corridor (AHU 18)	5

C8: Assumption on Occupancy/ Load Schedules indicating Percentage of Maximum Values in C3, C5 and C7

	Name of Schedule					
	Classroom (C)		Faculty Longue (F)		Restroom (R)	
Time	**Profile 1**	**Profile 2**	**Profile 1**	**Profile 2**	**Profile 1**	**Profile 2**
0:00	0	0	0	0	0	0
1:00	0	0	0	0	0	0
2:00	0	0	0	0	0	0
3:00	0	0	0	0	0	0
4:00	0	0	0	0	0	0
5:00	0	0	0	0	0	0
6:00	0	0	0	0	50	0
7:00	50	0	0	0	50	0
8:00	100	0	0	0	100	0
9:00	100	0	0	0	100	0
10:00	100	0	0	0	100	0
11:00	100	0	100	0	100	0
12:00	100	0	100	0	100	0
13:00	100	0	100	0	100	0
14:00	100	0	0	0	100	0
15:00	100	0	0	0	100	0
16:00	70	0	50	0	70	0
17:00	50	0	50	0	50	0
18:00	0	0	0	0	50	0
19:00	0	0	0	0	0	0
20:00	0	0	0	0	0	0
21:00	0	0	0	0	0	0
22:00	0	0	0	0	0	0
23:00	0	0	0	0	0	0

C9: Assignment of Schedules to Spaces

Room No	Room	Schedule	Room No	Room	Schedule	Room No	Room	Schedule
140	Mechanical Equipment	-	109	Secretary	C	237	Work Room	C
141	Electrical Equipment	-	111	Conference Room	C	243	Office	C
129	Classroom	C	108	Office	C	242	Storage Room	C
139	Cosmetology Lab	C	112	Storage	C	234	Office	C
135	Waiting	C	107	Storage	C	235	Office	C
101	Lobby 1	-	103	Corridor (AHU 6)	C	231	Copy Room	C
104	Classroom	C	103	Corridor (AHU 7)	C	228	Elect. Equip	-
105	Multi Purpose Science Lab	C	103	Corridor (AHU 8)	C	-	Elevator	-
106	Preparation Lab	C	122	Toilet	R	225	Office	C
113	Nursing Lab	C	121	Jan. Closet	R	224	Mechanical Equipment & Janitorial	-
116	Classroom	C	236	Typing Lab	C	246	Classroom	C
117	Lobby 2	-	238	Storage Room	C	240	Mechanical Equipment	-
119	Women's Toilet	R	239	Typing Room	C	206	Classroom	C
120	Men's Toilet	R	241	Computer Lab	C	208	Mechanical Equipment	-
123	Classroom	C	245	Storage Room	C	208A	Electrical Room	-
126	Classroom	C	244	Computer Lab	C	212	Double Office	C
128	Classroom	C	247	Classroom	C	211	Double Office	C
-	Passage 1	C	-	Lobby 1 (Upstairs)	-	210	Double Office	C
127	Department Head	C	202	Classroom	C	213	Office	C
-	Elevator	-	203	Classroom	C	214	Office	C
124	Mech. Room	-	204	Classroom	C	215	Office	C
131	Dispensary	C	205	Classroom	C	217	Office	C
134	Manicure	C	219	Faculty Longue	F	221	Ladies Toilet	R
133	Office	C	218	Department Head	C	220	Mens Toilet	R
132	Electrology	C	-	Lobby 2 Upstairs	-	216	Secretary (AHU 14)	C
138	Ladies Toilet	R	222	Women's Toilet	R	216	Secretary (AHU 15)	C
137	Mens Toilet	R	223	Men's Toilet	R	248	Passage	C
115	Classroom	C	226	Double Office	C	201	Corridor (AHU 14)	C
114	Mechanical Equipment	-	229	Department Head	C	201	Corridor (AHU 16)	C
114A	Electrical Equipment	-	230	Secretary	C	201	Corridor (AHU 17)	C
110	Department Head	C	233	Office	C	201	Corridor (AHU 18)	C

C10: 'Activity Level' for various spaces

Room No	Room	Activity Level	Room No	Room	Activity Level	Room No	Room	Activity Level
140	Mechanical Equipment	-	109	Secretary	Office Work	237	Work Room	Office Work
141	Electrical Equipment	-	111	Conference Room	Office Work	243	Office	Office Work
129	Classroom	Office Work	108	Office	Office Work	242	Storage Room	Sedentary Work
139	Cosmetology Lab	Medium Work	112	Storage	Sedentary Work	234	Office	Office Work
135	Waiting	Sedentary Work	107	Storage	Sedentary Work	235	Office	Office Work
101	Lobby 1	-	103	Corridor (AHU 6)	Office Work	231	Copy Room	Office Work
104	Classroom	Office Work	103	Corridor (AHU 7)	Office Work	228	Elect. Equip	-
105	Multi Purpose Science Lab	Sedentary Work	103	Corridor (AHU 8)	Office Work	-	Elevator	-
106	Preparation Lab	Medium Work	122	Toilet	Seated At Rest	225	Office	Office Work
113	Nursing Lab	Medium Work	121	Jan. Closet	Seated At Rest	224	Mechanical Equipment & Janitorial	-
116	Classroom	Office Work	236	Typing Lab	Sedentary Work	246	Classroom	Office Work
117	Lobby 2	-	238	Storage Room	Sedentary Work	240	Mechanical Equipment	-
119	Women's Toilet	Seated At Rest	239	Typing Room	Sedentary Work	206	Classroom	Office Work
120	Men's Toilet	Seated At Rest	241	Computer Lab	Office Work	208	Mechanical Equipment	-
123	Classroom	Office Work	245	Storage Room	Sedentary Work	208A	Electrical Room	-
126	Classroom	Office Work	244	Computer Lab	Office Work	212	Double Office	Office Work
128	Classroom	Office Work	247	Classroom	Office Work	211	Double Office	Office Work
-	Passage 1	Office Work	-	Lobby 1 (Upstairs)	-	210	Double Office	Office Work
127	Department Head	Office Work	202	Classroom	Office Work	213	Office	Office Work
-	Elevator	-	203	Classroom	Office Work	214	Office	Office Work
124	Mech. Room	-	204	Classroom	Office Work	215	Office	Office Work
131	Dispensary	Medium Work	205	Classroom	Office Work	217	Office	Office Work
134	Manicure	Medium Work	219	Faculty Longue	Seated At Rest	221	Ladies Toilet	Seated At Rest
133	Office	Office Work	218	Department Head	Office Work	220	Mens Toilet	Seated At Rest
132	Electrology	Sedentary Work	-	Lobby 2 Upstairs	-	216	Secretary (AHU 14)	Office Work
138	Ladies Toilet	Seated At Rest	222	Women's Toilet	Seated At Rest	216	Secretary (AHU 15)	Office Work
137	Mens Toilet	Seated At Rest	223	Men's Toilet	Seated At Rest	248	Passage	Office Work
115	Classroom	Office Work	226	Double Office	Office Work	201	Corridor (AHU 14)	Office Work
114	Mechanical Equipment	-	229	Department Head	Office Work	201	Corridor (AHU 16)	Office Work
114A	Electrical Equipment	-	230	Secretary	Office Work	201	Corridor (AHU 17)	Office Work
110	Department Head	Office Work	233	Office	Office Work	201	Corridor (AHU 18)	Office Work

C11: Estimation of Unmeasured SA CFM

AHU	$Area_{Space}$ (sq.ft.)	Design SA CFM	Measured SA CFM	D
1	2,109.00	3,000	2,202	26.60
2	883.00	1,000	931	6.90
3	1,405.38	1,200	1,372	-14.33
4	2,235.69	3,725	3,000	19.46
5	493.75	650	795	-22.31
6	1,485.63	2,475	2,529	-2.18
7	2,687.19	1,600	1,488	7.00
8	1,612.25	1,600	1,658	-3.63
13	1,351.00	1,800	1,558	13.44
14	2,018.69	1,800	1,685	6.39

D_A	7.08

AHU	Design SA CFM	Estimated SA CFM
9	2,400.00	2,230
10	1,600.00	1,487
11	1,400.00	1,301
12	1,200.00	1,115
15	800.00	743
16	2,000.00	1,858
17	1,800.00	1,672
18	1,800.00	1,672

C12: OA and Direct Exhaust for Simulation 1

AHU	Total Area	Air Quantity		Forced Exhaust Air Flow	Balanced Air Flows	Zone Direct Exhaust
		SA CFM	OA CFM			
1	2,109.00	2,202	55	1,254.37	0.0	1,254.37
2	883.00	931	15	0.00	5.9	5.89
3	1,405.38	1,372	72	41.63	28.3	69.89
4	2,235.69	3,000	37	132.26	0.0	132.26
5	493.75	795	88	0.00	34.5	34.53
6	1,485.63	2,529	311	0.00	122.0	122.03
7	2,687.19	1,488	43	0.00	16.9	16.87
8	1,612.25	1,658	911	0.00	357.5	357.46
9	1,399.41	2,230	30	122.74	0.0	122.74
10	917.50	1,487	128	0.00	50.2	50.22
11	1,478.63	1,301	107	0.00	42.0	41.98
12	1,197.63	1,115	64	0.00	25.1	25.11
13	1,351.00	1,558	16	0.00	6.3	6.28
14	2,018.69	1,685	140	0.00	54.9	54.93
15	514.81	743	79	101.00	0.0	101.00
16	1,479.38	1,858	115	0.00	45.1	45.12
17	1,682.31	1,672	123	0.00	48.3	48.26
18	1,317.25	1,672	255	0.00	100.1	100.06
Sum	26,268.47	29,297	2,589	1,652.00	937	2,589

Note: ‘Balanced Air Flows’ Column shows the difference of total OA CFM and total Exhaust Air Flow being divided among AHUs as described in Section 4.3.2.

C13: OA for Spaces in Simulation 1

Floor	Room No	Room	OA	Floor	Room No	Room	OA	Floor	Room No	Room	OA
1	140	Mechanical Equipment	0.0	1	109	Secretary	1.2	2	237	Work Room	14.1
1	141	Electrical Equipment	0.0	1	111	Conference Room	1.9	2	243	Office	6.4
1	129	Classroom	15.0	1	108	Office	1.2	2	242	Storage Room	8.6
1	139	Cosmetology Lab	55.0	1	112	Storage	2.2	2	234	Office	1.7
1	135	Waiting	14.9	1	107	Storage	2.2	2	235	Office	1.7
1	101	Lobby 1	0.0	1	103	Corridor (AHU 6)	168.6	2	231	Copy Room	1.3
1	104	Classroom	88.0	1	103	Corridor (AHU 7)	11.7	2	228	Elect. Equip	0.0
1	105	Multi Purpose Science Lab	15.9	1	103	Corridor (AHU 8)	130.0	2	-	Elevator	0.0
1	106	Preparation Lab	4.8	1	122	Toilet	0.6	2	225	Office	5.5
1	113	Nursing Lab	503.2	1	121	Jan. Closet	0.6	2	224	Mechanical Equipment & Janitorial	0.0
1	116	Classroom	277.8	2	236	Typing Lab	128.0	2	246	Classroom	31.6
1	117	Lobby 2	0.0	2	238	Storage Room	8.5	2	240	Mechanical Equipment	0.0
1	119	Women's Toilet	4.0	2	239	Typing Room	65.6	2	206	Classroom	37.2
1	120	Men's Toilet	4.1	2	241	Computer Lab	49.0	2	208	Mechanical Equipment	0.0
1	123	Classroom	7.7	2	245	Storage Room	1.1	2	208A	Electrical Room	0.0
1	126	Classroom	9.2	2	244	Computer Lab	10.8	2	212	Double Office	9.3
1	128	Classroom	10.8	2	247	Classroom	4.1	2	211	Double Office	9.3
1	-	Passage 1	6.2	2	-	Lobby 1 (Upstairs)	0.0	2	210	Double Office	9.3
1	127	Department Head	25.1	2	202	Classroom	39.1	2	213	Office	4.4
1	-	Elevator	0.0	2	203	Classroom	56.5	2	214	Office	4.4
1	124	Mech. Room	0.0	2	204	Classroom	96.4	2	215	Office	4.4
1	131	Dispensary	20.7	2	205	Classroom	133.5	2	217	Office	4.4
1	134	Manicure	4.7	2	219	Faculty Longue	36.3	2	221	Ladies Toilet	5.6
1	133	Office	6.5	2	218	Department Head	18.0	2	220	Mens Toilet	5.6
1	132	Electrology	15.5	2	-	Lobby 2 Upstairs	0.0	2	216	Secretary (AHU 14)	19.6
1	138	Ladies Toilet	1.8	2	222	Women's Toilet	5.6	2	216	Secretary (AHU 15)	13.7
1	137	Mens Toilet	1.8	2	223	Men's Toilet	4.8	2	248	Passage	18.8
1	115	Classroom	117.2	2	226	Double Office	3.4	2	201	Corridor (AHU 14)	69.3
1	114	Mechanical Equipment	0.0	2	229	Department Head	2.4	2	201	Corridor (AHU 16)	19.4
1	114A	Electrical Equipment	0.0	2	230	Secretary	7.4	2	201	Corridor (AHU 17)	54.2
1	110	Department Head	1.9	2	233	Office	1.7	2	201	Corridor (AHU 18)	25.1

C14: OA, Direct Exhaust and Zone Infiltration for Simulation 2

AHU	Total Area	Air Quantity		Forced Exhaust Air Flow	Zone Direct Exhaust	Zone Infiltration
		SA CFM	OA CFM			
1	2,109.00	2,202	35	1254.4	1,254.4	0.0
2	883.00	931	10	0.0	0.0	0.0
3	1,405.38	1,372	46	41.6	41.6	0.0
4	2,235.69	3,000	24	132.3	132.3	0.0
5	493.75	795	56	0.0	0.0	0.0
6	1,485.63	2,529	198	0.0	0.0	0.0
7	2,687.19	1,488	27	0.0	0.0	0.0
8	1,612.25	1,658	581	0.0	0.0	0.0
9	1,399.41	2,230	19	122.7	122.7	0.0
10	917.50	1,487	82	0.0	0.0	0.0
11	1,478.63	1,301	68	0.0	0.0	0.0
12	1,197.63	1,115	41	0.0	0.0	0.0
13	1,351.00	1,558	10	0.0	0.0	0.0
14	2,018.69	1,685	89	0.0	0.0	0.0
15	514.81	743	50	101.0	101.0	0.0
16	1,479.38	1,858	73	0.0	0.0	0.0
17	1,682.31	1,672	78	0.0	0.0	0.0
18	1,317.25	1,672	163	0.0	0.0	0.0
Sum	26,268.47	29,297	1,652	1,652	1,652	0.0

C15: OA for Spaces in Simulation 2

Floor	Room No	Room	OA	Floor	Room No	Room	OA	Floor	Room No	Room	OA
1	140	Mechanical Equipment	0.0	1	109	Secretary	0.8	2	237	Work Room	9.0
1	141	Electrical Equipment	0.0	1	111	Conference Room	1.2	2	243	Office	4.1
1	129	Classroom	9.6	1	108	Office	0.8	2	242	Storage Room	5.5
1	139	Cosmetology Lab	35.1	1	112	Storage	1.4	2	234	Office	1.1
1	135	Waiting	9.5	1	107	Storage	1.4	2	235	Office	1.1
1	101	Lobby 1	0.0	1	103	Corridor (AHU 6)	107.6	2	231	Copy Room	0.8
1	104	Classroom	56.2	1	103	Corridor (AHU 7)	7.5	2	228	Elect. Equip	0.0
1	105	Multi Purpose Science Lab	10.2	1	103	Corridor (AHU 8)	82.9	2	-	Elevator	0.0
1	106	Preparation Lab	3.0	1	122	Toilet	0.4	2	225	Office	3.5
1	113	Nursing Lab	321.1	1	121	Jan. Closet	0.4	2	224	Mechanical Equipment & Janitorial	0.0
1	116	Classroom	177.3	2	236	Typing Lab	81.7	2	246	Classroom	20.2
1	117	Lobby 2	0.0	2	238	Storage Room	5.4	2	240	Mechanical Equipment	0.0
1	119	Women's Toilet	2.5	2	239	Typing Room	41.9	2	206	Classroom	23.7
1	120	Men's Toilet	2.6	2	241	Computer Lab	31.3	2	208	Mechanical Equipment	0.0
1	123	Classroom	4.9	2	245	Storage Room	0.7	2	208A	Electrical Room	0.0
1	126	Classroom	5.9	2	244	Computer Lab	6.9	2	212	Double Office	5.9
1	128	Classroom	6.9	2	247	Classroom	2.6	2	211	Double Office	5.9
1	-	Passage 1	4.0	2	-	Lobby 1 (Upstairs)	0.0	2	210	Double Office	5.9
1	127	Department Head	16.0	2	202	Classroom	25.0	2	213	Office	2.8
1	-	Elevator	0.0	2	203	Classroom	36.0	2	214	Office	2.8
1	124	Mech. Room	0.0	2	204	Classroom	61.5	2	215	Office	2.8
1	131	Dispensary	13.2	2	205	Classroom	85.2	2	217	Office	2.8
1	134	Manicure	3.0	2	219	Faculty Longue	23.1	2	221	Ladies Toilet	3.5
1	133	Office	4.1	2	218	Department Head	11.5	2	220	Mens Toilet	3.5
1	132	Electrology	9.9	2	-	Lobby 2 Upstairs	0.0	2	216	Secretary (AHU 14)	12.5
1	138	Ladies Toilet	1.1	2	222	Women's Toilet	3.6	2	216	Secretary (AHU 15)	8.7
1	137	Mens Toilet	1.1	2	223	Men's Toilet	3.1	2	248	Passage	12.0
1	115	Classroom	74.8	2	226	Double Office	2.1	2	201	Corridor (AHU 14)	44.2
1	114	Mechanical Equipment	0.0	2	229	Department Head	1.5	2	201	Corridor (AHU 16)	12.4
1	114A	Electrical Equipment	0.0	2	230	Secretary	4.7	2	201	Corridor (AHU 17)	34.6
1	110	Department Head	1.2	2	233	Office	1.1	2	201	Corridor (AHU 18)	16.0

C16: OA and Zone Infiltration for Simulation 3

AHU	Total Area	Air Quantity		Forced Exhaust Air Flow	(Forced Exhaust Air Flow - OA CFM)	Zone Infiltration
		SA CFM	OA CFM			
1	2,109.00	2,202	21.24	1,254.37	1,233.12	131.4
2	883.00	931	5.79	0.00	-5.79	0.0
3	1,405.38	1,372	27.81	41.63	13.82	172.0
4	2,235.69	3,000	14.29	132.26	117.97	88.4
5	493.75	795	33.99	0.00	-33.99	0.0
6	1,485.63	2,529	120.12	0.00	-120.12	0.0
7	2,687.19	1,488	16.61	0.00	-16.61	0.0
8	1,612.25	1,658	351.87	0.00	-351.87	0.0
9	1,399.41	2,230	11.59	122.74	111.15	71.6
10	917.50	1,487	49.44	0.00	-49.44	0.0
11	1,478.63	1,301	41.33	0.00	-41.33	0.0
12	1,197.63	1,115	24.72	0.00	-24.72	0.0
13	1,351.00	1,558	6.18	0.00	-6.18	0.0
14	2,018.69	1,685	54.07	0.00	-54.07	0.0
15	514.81	743	30.51	101.00	70.49	188.7
16	1,479.38	1,858	44.42	0.00	-44.42	0.0
17	1,682.31	1,672	47.51	0.00	-47.51	0.0
18	1,317.25	1,672	98.49	0.00	-98.49	0.0
Sum	26,268.47	29,297	1,000	1,652.00	652	652

C17: OA for Spaces in Simulation 3

Floor	Room No	Room	OA	Floor	Room No	Room	OA	Floor	Room No	Room	OA
1	140	Mechanical Equipment	0.0	1	109	Secretary	0.5	2	237	Work Room	5.5
1	141	Electrical Equipment	0.0	1	111	Conference Room	0.7	2	243	Office	2.5
1	129	Classroom	5.8	1	108	Office	0.5	2	242	Storage Room	3.3
1	139	Cosmetology Lab	21.2	1	112	Storage	0.8	2	234	Office	0.6
1	135	Waiting	5.7	1	107	Storage	0.8	2	235	Office	0.6
1	101	Lobby 1	0.0	1	103	Corridor (AHU 6)	65.1	2	231	Copy Room	0.5
1	104	Classroom	34.0	1	103	Corridor (AHU 7)	4.5	2	228	Elect. Equip	0.0
1	105	Multi Purpose Science Lab	6.1	1	103	Corridor (AHU 8)	50.2	2	-	Elevator	0.0
1	106	Preparation Lab	1.8	1	122	Toilet	0.2	2	225	Office	2.1
1	113	Nursing Lab	194.4	1	121	Jan. Closet	0.2	2	224	Mechanical Equipment & Janitorial	0.0
1	116	Classroom	107.3	2	236	Typing Lab	49.4	2	246	Classroom	12.2
1	117	Lobby 2	0.0	2	238	Storage Room	3.3	2	240	Mechanical Equipment	0.0
1	119	Women's Toilet	1.5	2	239	Typing Room	25.4	2	206	Classroom	14.4
1	120	Men's Toilet	1.6	2	241	Computer Lab	18.9	2	208	Mechanical Equipment	0.0
1	123	Classroom	3.0	2	245	Storage Room	0.4	2	208A	Electrical Room	0.0
1	126	Classroom	3.6	2	244	Computer Lab	4.2	2	212	Double Office	3.6
1	128	Classroom	4.2	2	247	Classroom	1.6	2	211	Double Office	3.6
1	-	Passage 1	2.4	2	-	Lobby 1 (Upstairs)	0.0	2	210	Double Office	3.6
1	127	Department Head	9.7	2	202	Classroom	15.1	2	213	Office	1.7
1	-	Elevator	0.0	2	203	Classroom	21.8	2	214	Office	1.7
1	124	Mech. Room	0.0	2	204	Classroom	37.2	2	215	Office	1.7
1	131	Dispensary	8.0	2	205	Classroom	51.6	2	217	Office	1.7
1	134	Manicure	1.8	2	219	Faculty Longue	14.0	2	221	Ladies Toilet	2.1
1	133	Office	2.5	2	218	Department Head	6.9	2	220	Mens Toilet	2.1
1	132	Electrology	6.0	2	-	Lobby 2 Upstairs	0.0	2	216	Secretary (AHU 14)	7.6
1	138	Ladies Toilet	0.7	2	222	Women's Toilet	2.2	2	216	Secretary (AHU 15)	5.3
1	137	Mens Toilet	0.7	2	223	Men's Toilet	1.9	2	248	Passage	7.3
1	115	Classroom	45.3	2	226	Double Office	1.3	2	201	Corridor (AHU 14)	26.8
1	114	Mechanical Equipment	0.0	2	229	Department Head	0.9	2	201	Corridor (AHU 16)	7.5
1	114A	Electrical Equipment	0.0	2	230	Secretary	2.9	2	201	Corridor (AHU 17)	20.9
1	110	Department Head	0.7	2	233	Office	0.6	2	201	Corridor (AHU 18)	9.7

C18: Infiltration for spaces in Simulation 3

Floor	Room No	Room	Infiltration	Floor	Room No	Room	Infiltration	Floor	Room No	Room	Infiltration
1	140	Mechanical Equipment	0.0	1	109	Secretary	0.0	2	237	Work Room	0.0
1	141	Electrical Equipment	0.0	1	111	Conference Room	0.0	2	243	Office	0.0
1	129	Classroom	0.0	1	108	Office	0.0	2	242	Storage Room	0.0
1	139	Cosmetology Lab	131.4	1	112	Storage	0.0	2	234	Office	4.0
1	135	Waiting	35.5	1	107	Storage	0.0	2	235	Office	4.0
1	101	Lobby 1	0.0	1	103	Corridor (AHU 6)	0.0	2	231	Copy Room	3.2
1	104	Classroom	0.0	1	103	Corridor (AHU 7)	0.0	2	228	Elect. Equip	0.0
1	105	Multi Purpose Science Lab	0.0	1	103	Corridor (AHU 8)	0.0	2	-	Elevator	0.0
1	106	Preparation Lab	0.0	1	122	Toilet	1.3	2	225	Office	0.0
1	113	Nursing Lab	0.0	1	121	Jan. Closet	1.4	2	224	Mechanical Equipment & Janitorial	0.0
1	116	Classroom	0.0	2	236	Typing Lab	0.0	2	246	Classroom	0.0
1	117	Lobby 2	0.0	2	238	Storage Room	0.0	2	240	Mechanical Equipment	0.0
1	119	Women's Toilet	9.5	2	239	Typing Room	0.0	2	206	Classroom	0.0
1	120	Men's Toilet	9.9	2	241	Computer Lab	0.0	2	208	Mechanical Equipment	0.0
1	123	Classroom	18.3	2	245	Storage Room	0.0	2	208A	Electrical Room	0.0
1	126	Classroom	22.1	2	244	Computer Lab	0.0	2	212	Double Office	0.0
1	128	Classroom	25.9	2	247	Classroom	0.0	2	211	Double Office	0.0
1	-	Passage 1	14.8	2	-	Lobby 1 (Upstairs)	0.0	2	210	Double Office	0.0
1	127	Department Head	0.0	2	202	Classroom	0.0	2	213	Office	0.0
1	-	Elevator	0.0	2	203	Classroom	0.0	2	214	Office	0.0
1	124	Mech. Room	0.0	2	204	Classroom	0.0	2	215	Office	0.0
1	131	Dispensary	49.6	2	205	Classroom	0.0	2	217	Office	0.0
1	134	Manicure	11.1	2	219	Faculty Longue	86.6	2	221	Ladies Toilet	13.3
1	133	Office	15.4	2	218	Department Head	42.9	2	220	Mens Toilet	13.3
1	132	Electrology	37.0	2	-	Lobby 2 Upstairs	0.0	2	216	Secretary (AHU 14)	0.0
1	138	Ladies Toilet	4.3	2	222	Women's Toilet	13.4	2	216	Secretary (AHU 15)	32.6
1	137	Mens Toilet	4.3	2	223	Men's Toilet	11.6	2	248	Passage	0.0
1	115	Classroom	0.0	2	226	Double Office	8.0	2	201	Corridor (AHU 14)	0.0
1	114	Mechanical Equipment	0.0	2	229	Department Head	5.8	2	201	Corridor (AHU 16)	0.0
1	114A	Electrical Equipment	0.0	2	230	Secretary	17.7	2	201	Corridor (AHU 17)	0.0
1	110	Department Head	0.0	2	233	Office	4.0	2	201	Corridor (AHU 18)	0.0

C19: OA and Direct Exhaust for Simulation 4

AHU	Total Area	Air Quantity		Forced Exhaust Air Flow	Zone Direct Exhaust
		SA CFM	OA CFM		
1	2,109.00	3,000	2,100	1,254.4	2,100
2	883.00	1,000	100	0.0	100
3	1,405.38	1,200	125	41.6	125
4	2,235.69	3,725	250	132.3	250
5	493.75	650	100	0.0	100
6	1,485.63	2,475	275	0.0	275
7	2,687.19	1,600	125	0.0	125
8	1,612.25	1,600	175	0.0	175
9	1,399.41	2,400	150	122.7	150
10	917.50	1,600	100	0.0	100
11	1,478.63	1,400	125	0.0	125
12	1,197.63	1,200	125	0.0	125
13	1,351.00	1,800	150	0.0	150
14	2,018.69	1,800	200	0.0	200
15	514.81	800	75	101.0	75
16	1,479.38	2,000	155	0.0	155
17	1,682.31	1,800	175	0.0	175
18	1,317.25	1,800	150	0.0	150
Sum	26,268.47	31,850	4,655	1,652	4,655

C20: OA for Spaces in Simulation 4

Floor	Room No	Room	OA	Floor	Room No	Room	OA	Floor	Room No	Room	OA
1	140	Mechanical Equipment	0.0	1	109	Secretary	3.6	2	237	Work Room	16.5
1	141	Electrical Equipment	0.0	1	111	Conference Room	5.4	2	243	Office	12.5
1	129	Classroom	100.0	1	108	Office	3.6	2	242	Storage Room	16.7
1	139	Cosmetology Lab	2,100.0	1	112	Storage	6.3	2	234	Office	8.4
1	135	Waiting	25.8	1	107	Storage	6.3	2	235	Office	8.4
1	101	Lobby 1	0.0	1	103	Corridor (AHU 6)	149.1	2	231	Copy Room	6.6
1	104	Classroom	100.0	1	103	Corridor (AHU 7)	34.1	2	228	Elect. Equip	0.0
1	105	Multi Purpose Science Lab	46.3	1	103	Corridor (AHU 8)	25.0	2	-	Elevator	0.0
1	106	Preparation Lab	13.9	1	122	Toilet	3.8	2	225	Office	7.8
1	113	Nursing Lab	96.7	1	121	Jan. Closet	4.0	2	224	Mechanical Equipment & Janitorial	0.0
1	116	Classroom	53.4	2	236	Typing Lab	100.0	2	246	Classroom	44.9
1	117	Lobby 2	0.0	2	238	Storage Room	9.9	2	240	Mechanical Equipment	0.0
1	119	Women's Toilet	26.9	2	239	Typing Room	76.7	2	206	Classroom	52.9
1	120	Men's Toilet	28.0	2	241	Computer Lab	95.8	2	208	Mechanical Equipment	0.0
1	123	Classroom	51.7	2	245	Storage Room	10.3	2	208A	Electrical Room	0.0
1	126	Classroom	62.4	2	244	Computer Lab	101.3	2	212	Double Office	13.3
1	128	Classroom	73.2	2	247	Classroom	38.5	2	211	Double Office	13.3
1	-	Passage 1	10.8	2	-	Lobby 1 (Upstairs)	0.0	2	210	Double Office	13.3
1	127	Department Head	22.2	2	202	Classroom	52.8	2	213	Office	6.3
1	-	Elevator	0.0	2	203	Classroom	76.1	2	214	Office	6.3
1	124	Mech. Room	0.0	2	204	Classroom	56.7	2	215	Office	6.3
1	131	Dispensary	36.0	2	205	Classroom	78.5	2	217	Office	6.3
1	134	Manicure	8.1	2	219	Faculty Longue	34.4	2	221	Ladies Toilet	5.3
1	133	Office	11.2	2	218	Department Head	17.0	2	220	Mens Toilet	5.3
1	132	Electrology	26.9	2	-	Lobby 2 Upstairs	0.0	2	216	Secretary (AHU 14)	28.0
1	138	Ladies Toilet	3.1	2	222	Women's Toilet	28.0	2	216	Secretary (AHU 15)	13.0
1	137	Mens Toilet	3.1	2	223	Men's Toilet	24.2	2	248	Passage	21.9
1	115	Classroom	103.7	2	226	Double Office	16.8	2	201	Corridor (AHU 14)	99.0
1	114	Mechanical Equipment	0.0	2	229	Department Head	12.1	2	201	Corridor (AHU 16)	26.1
1	114A	Electrical Equipment	0.0	2	230	Secretary	37.1	2	201	Corridor (AHU 17)	77.2
1	110	Department Head	5.4	2	233	Office	8.4	2	201	Corridor (AHU 18)	14.8

C21: OA and Direct Exhaust for Simulation 5

AHU	Total Area	Air Quantity		Forced Exhaust Air Flow	Zone Direct Exhaust
		SA CFM	OA CFM		
1	2,109.00	5,190	1,254	1,254	1,254
2	883.00	2,292	436	0	436
3	1,405.38	2,827	555	42	555
4	2,235.69	5,779	1,332	132	1,332
5	493.75	1,264	389	0	389
6	1,485.63	1,654	458	0	458
7	2,687.19	8,091	903	0	903
8	1,612.25	3,386	923	0	923
9	1,399.41	4,147	254	123	254
10	917.50	3,430	220	0	220
11	1,478.63	3,587	291	0	291
12	1,197.63	3,186	261	0	261
13	1,351.00	5,086	602	0	602
14	2,018.69	2,715	207	0	207
15	514.81	3,286	131	101	131
16	1,479.38	5,294	823	0	823
17	1,682.31	2,954	817	0	817
18	1,317.25	2,830	810	0	810
Sum	26,268.47	66,998	10,666	1,652	10,666

NOTE: Please refer to the section 4.3.3 (b) for additional comments.

C22:OA for Spaces in Simulation 5

Floor	Room No	Room	OA Designation	Floor	Room No	Room	OA Designation	Floor	Room No	Room	OA Designation
1	140	Mechanical Equipment	O 9	1	109	Secretary	O 12	2	237	Work Room	O 12
1	141	Electrical Equipment	O 9	1	111	Conference Room	O 5	2	243	Office	O 12
1	129	Classroom	O 1	1	108	Office	O 12	2	242	Storage Room	O 7
1	139	Cosmetology Lab	O 3	1	112	Storage	O 7	2	234	Office	O 12
1	135	Waiting	O 13	1	107	Storage	O 7	2	235	Office	O 12
1	101	Lobby 1	O 11	1	103	Corridor (AHU 6)	O 6	2	231	Copy Room	O 12
1	104	Classroom	O 1	1	103	Corridor (AHU 7)	O 6	2	228	Elect. Equip	O 9
1	105	Multi Purpose Science Lab	O 3	1	103	Corridor (AHU 8)	O 6	2	-	Elevator	O 10
1	106	Preparation Lab	O 3	1	122	Toilet	O 4	2	225	Office	O 12
1	113	Nursing Lab	O 3	1	121	Jan. Closet	O 7	2	224	Mechanical Equipment & Janitorial	O 9
1	116	Classroom	O 1	2	236	Typing Lab	O 8	2	246	Classroom	O 1
1	117	Lobby 2	O 11	2	238	Storage Room	O 7	2	240	Mechanical Equipment	O 9
1	119	Women's Toilet	O 4	2	239	Typing Room	O 8	2	206	Classroom	O 1
1	120	Men's Toilet	O 4	2	241	Computer Lab	O 8	2	208	Mechanical Equipment	O 9
1	123	Classroom	O 1	2	245	Storage Room	O 7	2	208A	Electrical Room	O 9
1	126	Classroom	O 1	2	244	Computer Lab	O 8	2	212	Double Office	O 12
1	128	Classroom	O 1	2	247	Classroom	O 1	2	211	Double Office	O 12
1	-	Passage 1	O 6	2	-	Lobby 1 (Upstairs)	O 11	2	210	Double Office	O 12
1	127	Department Head	O 12	2	202	Classroom	O 1	2	213	Office	O 12
1	-	Elevator	O 10	2	203	Classroom	O 1	2	214	Office	O 12
1	124	Mech. Room	O 9	2	204	Classroom	O 1	2	215	Office	O 12
1	131	Dispensary	O 2	2	205	Classroom	O 1	2	217	Office	O 12
1	134	Manicure	O 3	2	219	Faculty Longue	O 4	2	221	Ladies Toilet	O 4
1	133	Office	O 12	2	218	Department Head	O 12	2	220	Mens Toilet	O 4
1	132	Electrology	O 3	2	-	Lobby 2 Upstairs	O 11	2	216	Secretary (AHU 14)	O 12
1	138	Ladies Toilet	O 4	2	222	Women's Toilet	O 4	2	216	Secretary (AHU 15)	O 12
1	137	Mens Toilet	O 4	2	223	Men's Toilet	O 4	2	248	Passage	O 6
1	115	Classroom	O 1	2	226	Double Office	O 12	2	201	Corridor (AHU 14)	O 6
1	114	Mechanical Equipment	O 9	2	229	Department Head	O 12	2	201	Corridor (AHU 16)	O 6
1	114A	Electrical Equipment	O 9	2	230	Secretary	O 12	2	201	Corridor (AHU 17)	O 6
1	110	Department Head	O 12	2	233	Office	O 12	2	201	Corridor (AHU 18)	O 6

NOTE: The ‘OA Designations’ have been indicated in Section 4.3.3 (b).

APPENDIX D: RESULTS

D1: Results of Simulation 1; AHU 8 Design – Air System Sizing Summary

Air System Information

Air System Name	AHU 8	Number of zones	1
Equipment Class	CW AHU	Floor Area	1612.2 ft²
Air System Type	SZCAV	Location	Wilmington, North Carolina

Sizing Calculation Information

Zone and Space Sizing Method:

Zone CFM	Sum of space airflow rates	Calculation Months	Jan to Dec
Space CFM	Individual peak space loads	Sizing Data	User-Modified

Central Cooling Coil Sizing Data

Total coil load	10.1	Tons	Load occurs at	Jul 1500	
Total coil load	121.4	MBH	OA DB / WB	92.5 / 78.9	°F
Sensible coil load	64.4	MBH	Entering DB / WB	87.9 / 74.3	°F
Coil CFM at Jul 1500	1658	CFM	Leaving DB / WB	51.9 / 51.2	°F
Max block CFM	1658	CFM	Coil ADP	47.9	°F
Sum of peak zone CFM	1658	CFM	Bypass Factor	0.100	
Sensible heat ratio	0.531		Resulting RH	48	%
ft²/Ton	159.4		Design supply temp.	59.0	°F
BTU/(hr-ft²)	75.3		Zone T-stat Check	0 of 1	OK
Water flow @ 10.0 °F rise	24.29	gpm	Max zone temperature deviation	10.8	°F

Central Heating Coil Sizing Data

Max coil load	27.2	MBH	Load occurs at	Des Htg	
Coil CFM at Des Htg	1658	CFM	BTU/(hr-ft²)	16.9	
Max coil CFM	1658	CFM	Ent. DB / Lvg DB	50.0 / 65.2	°F
Water flow @ 20.0 °F drop	N/A				

Preheat Coil Sizing Data

Max coil load	12.0	MBH	Load occurs at	Des Htg	
Coil CFM at Des Htg	1658	CFM	Ent. DB / Lvg DB	43.3 / 50.0	°F
Max coil CFM	1658	CFM			
Water flow @ 20.0 °F drop	N/A				

Supply Fan Sizing Data

Actual max CFM	1658	CFM	Fan motor BHP	5.00	BHP
Standard CFM	1656	CFM	Fan motor kW	3.73	kW
Actual max CFM/ft²	1.03	CFM/ft²			

Outdoor Ventilation Air Data

Design airflow CFM	911	CFM	CFM/person	10.24	CFM/person
CFM/ft²	0.57	CFM/ft²			

D2: Results of Simulation 1; AHU 8 Design: Zone Sizing and Space Loads

Air System Information

Air System Name .... **AHU 8**
Equipment Class .... **CW AHU**
Air System Type .... **SZCAV**

Number of zones **1**
Floor Area .... **1612.2** ft²
Location .... **Wilmington, North Carolina**

Sizing Calculation Information

Zone and Space Sizing Method:
Zone CFM .... **Sum of space airflow rates**
Space CFM .... **Individual peak space loads**

Calculation Months .... **Jan to Dec**
Sizing Data .... **User-Modified**

Zone Sizing Data

Zone Name	Maximum Cooling Sensible (MBH)	Design Air Flow (CFM)	Minimum Air Flow (CFM)	Time of Peak Load	Maximum Heating Load (MBH)	Zone Floor Area (ft²)	Zone CFM/ft²
Zone 1	43.8	1658	1658	Jun 1500	6.9	1612.2	1.03

Zone Terminal Sizing Data

No Zone Terminal Sizing Data required for this system.

Space Loads and Airflows

Zone Name / Space Name	Mult.	Cooling Sensible (MBH)	Time of Load	Air Flow (CFM)	Heating Load (MBH)	Floor Area (ft²)	Space CFM/ft²
Zone 1							
113 - Nursing Lab	1	23.2	Jun 1500	1955	5.0	890.6	2.20
116 - Classroom	1	11.8	Jul 1500	997	1.9	491.6	2.03
103 - Corridor (AHU 8)	1	8.8	Jan 1500	741	0.0	230.0	3.22

D3: Results of Simulation 1; AHU 8 Design: Zone Loads

	DESIGN COOLING			DESIGN HEATING		
	COOLING DATA AT Jul 1500 COOLING OA DB / WB 92.5 °F / 78.9 °F			HEATING DATA AT DES HTG HEATING OA DB / WB 23.0 °F / 19.2 °F		
ZONE LOADS	Details	Sensible (BTU/hr)	Latent (BTU/hr)	Details	Sensible (BTU/hr)	Latent (BTU/hr)
Window & Skylight Solar Loads	104 ft²	2193	-	104 ft²	-	-
Wall Transmission	595 ft²	1230	-	595 ft²	2852	-
Roof Transmission	0 ft²	0	-	0 ft²	0	-
Window Transmission	104 ft²	1203	-	104 ft²	2752	-
Skylight Transmission	0 ft²	0	-	0 ft²	0	-
Door Loads	0 ft²	0	-	0 ft²	0	-
Floor Transmission	1612 ft²	0	-	1612 ft²	1323	-
Partitions	0 ft²	0	-	0 ft²	0	-
Ceiling	0 ft²	0	-	0 ft²	0	-
Overhead Lighting	3634 W	9809	-	0	0	-
Task Lighting	0 W	0	-	0	0	-
Electric Equipment	3820 W	11819	-	0	0	-
People	89	17446	27245	0	0	0
Infiltration	-	0	0	-	0	0
Miscellaneous	-	0	0	-	0	0
Safety Factor	0% / 0%	0	0	0%	0	0
>> Total Zone Loads	-	43701	27245	-	6926	0
Zone Conditioning	-	41646	27245	-	7661	0
Plenum Wall Load	0%	0	-	0	0	-
Plenum Roof Load	0%	0	-	0	0	-
Plenum Lighting Load	0%	0	-	0	0	-
Return Fan Load	1301 CFM	0	-	1301 CFM	0	-
Ventilation Load	911 CFM	10067	29720	911 CFM	44281	0
Supply Fan Load	1658 CFM	12722	-	1658 CFM	-12722	-
Space Fan Coil Fans	-	0	-	-	0	-
Duct Heat Gain / Loss	0%	0	-	0%	0	-
>> Total System Loads	-	64435	56965	-	39220	0
Central Cooling Coil	-	64435	56965	-	0	0
Central Heating Coil	-	0	-	-	27241	-
Preheat Coil	-	0	-	-	11980	-
>> Total Conditioning	-	64435	56965	-	39220	0
Key:	Positive values are clg loads Negative values are htg loads			Positive values are htg loads Negative values are clg loads		

D4: Results of Simulation 1; System Psychrometrics for AHU 8

July DESIGN COOLING DAY, 1500

TABLE 1: SYSTEM DATA

Component	Location	Dry-Bulb Temp (°F)	Specific Humidity (lb/lb)	Airflow (CFM)	CO2 Level (ppm)	Sensible Heat (BTU/hr)	Latent Heat (BTU/hr)
Ventilation Air	Inlet	92.5	0.01820	911	400	10067	29720
Vent - Return Mixing	Outlet	87.9	0.01510	1658	1065	-	-
Preheat Coil	Outlet	87.9	0.01510	1658	1065	0	-
Central Cooling Coil	Outlet	51.9	0.00785	1658	1065	64435	56965
Central Heating Coil	Outlet	51.9	0.00785	1658	1065	0	-
Supply Fan	Outlet	59.0	0.00785	1658	1065	12722	-
Cold Supply Duct	Outlet	59.0	0.00785	1658	1065	-	-
Zone Air	-	82.3	0.01132	1658	1877	41646	27245
Zone Direct Exhaust	Outlet	82.3	0.01132	358	1877	-	-
Return Plenum	Outlet	82.3	0.01132	1301	1877	0	-

Air Density x Heat Capacity x Conversion Factor: At sea level = 1.080; At site altitude = 1.079 BTU/(hr-CFM-F)
Air Density x Heat of Vaporization x Conversion Factor: At sea level = 4746.6; At site altitude = 4740.9 BTU/(hr-CFM)
Site Altitude = 33.0 ft

TABLE 2: ZONE DATA

Zone Name	Zone Sensible Load (BTU/hr)	T-stat Mode	Zone Cond (BTU/hr)	Zone Temp (°F)	Zone Airflow (CFM)	CO2 Level (ppm)	Terminal Heating Coil (BTU/hr)	Zone Heating Unit (BTU/hr)
Zone 1	43701	Cooling	41646	82.3	1658	1877	0	0

Data for: July DESIGN COOLING DAY, 1500

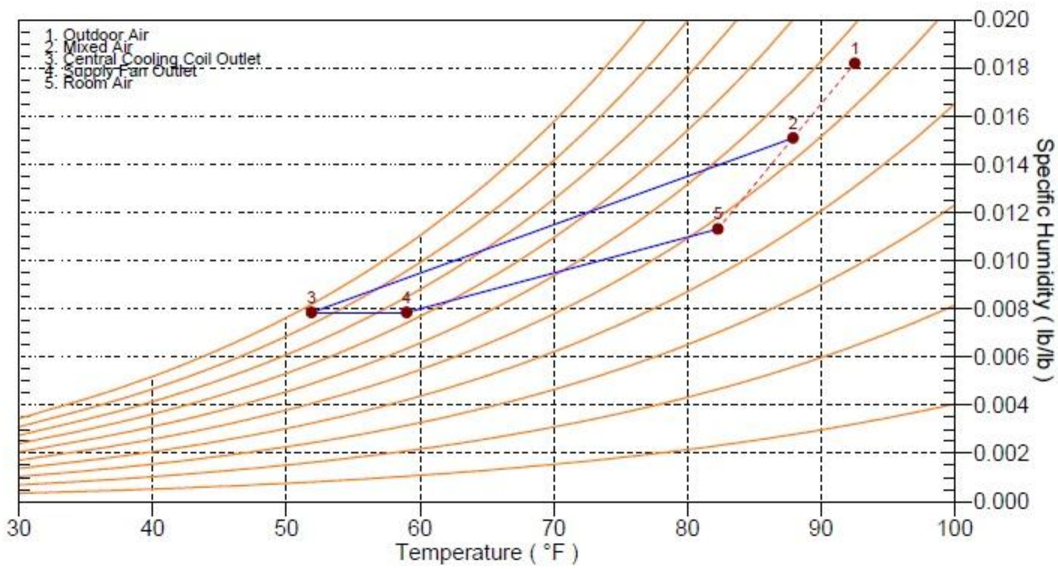


Fig. D5: Results of Simulation 1; Psychrometric Analysis of AHU 8

D6: Results of Simulation 1; Chiller Design

1. Plant Information:

Plant Name .... **Chiller**
Plant Type .... **Chiller Plant**
Design Weather .... **Wilmington, North Carolina**

2. Cooling Plant Sizing Data:

Maximum Plant Load .... **105.6** Tons
Load occurs at .... **Jul 1500**
ft²/Ton .... **248.1** ft²/Ton
Floor area served by plant .... **26205.1** ft²

3. Coincident Air System Cooling Loads for Jul 1500

Air System Name	Mult.	System Cooling Coil Load (Tons)
AHU 1	1	7.5
AHU 2	1	3.2
AHU 3	1	5.1
AHU 4	1	9.1
AHU 5	1	3.2
AHU 6	1	4.4
AHU 7	1	8.0
AHU 8	1	10.1
AHU 9	1	5.4
AHU 10	1	5.2
AHU 11	1	5.0
AHU 12	1	4.2
AHU 13	1	6.2
AHU 14	1	4.6
AHU 15	1	3.0
AHU 16	1	9.9
AHU 17	1	5.4
AHU 18	1	6.1

D7: Results of Simulation 1; Boiler Design

1. Plant Information:

Plant Name	**Boiler**
Plant Type	**Steam Boiler Plant**
Design Weather	**Wilmington, North Carolina**

2. Heating Plant Sizing Data:

Maximum Plant Load	**111.5**	MBH
Load occurs at	**Winter Design**	
BTU/(hr-ft²)	**4.3**	BTU/(hr-ft²)
Floor area served by plant	**26205.1**	ft²

3. Coincident Air System Heating Loads for Winter Design

Air System Name	Mult.	System Heating Coil Load (MBH)
AHU 1	1	2.0
AHU 2	1	0.0
AHU 3	1	0.0
AHU 4	1	0.0
AHU 5	1	0.6
AHU 6	1	8.0
AHU 7	1	5.0
AHU 8	1	39.2
AHU 9	1	4.4
AHU 10	1	8.2
AHU 11	1	5.3
AHU 12	1	4.4
AHU 13	1	3.9
AHU 14	1	4.6
AHU 15	1	0.4
AHU 16	1	6.4
AHU 17	1	5.8
AHU 18	1	13.3

D8: Results of Simulation 1; Annual Cost Summary

Annual Costs

Component	Brunswick Community College ($)
Air System Fans	10,170
Cooling	16,238
Heating	33
Pumps	0
Cooling Tower Fans	0
HVAC Sub-Total	**26,441**
Lights	9,130
Electric Equipment	18,809
Misc. Electric	0
Misc. Fuel Use	0
Non-HVAC Sub-Total	**27,939**
Grand Total	**54,379**

Annual Cost per Unit Floor Area

Component	Brunswick Community College ($/ft²)
Air System Fans	0.388
Cooling	0.620
Heating	0.001
Pumps	0.000
Cooling Tower Fans	0.000
HVAC Sub-Total	**1.009**
Lights	0.348
Electric Equipment	0.718
Misc. Electric	0.000
Misc. Fuel Use	0.000
Non-HVAC Sub-Total	**1.066**
Grand Total	**2.075**
Gross Floor Area (ft²)	26205.1
Conditioned Floor Area (ft²)	26205.1

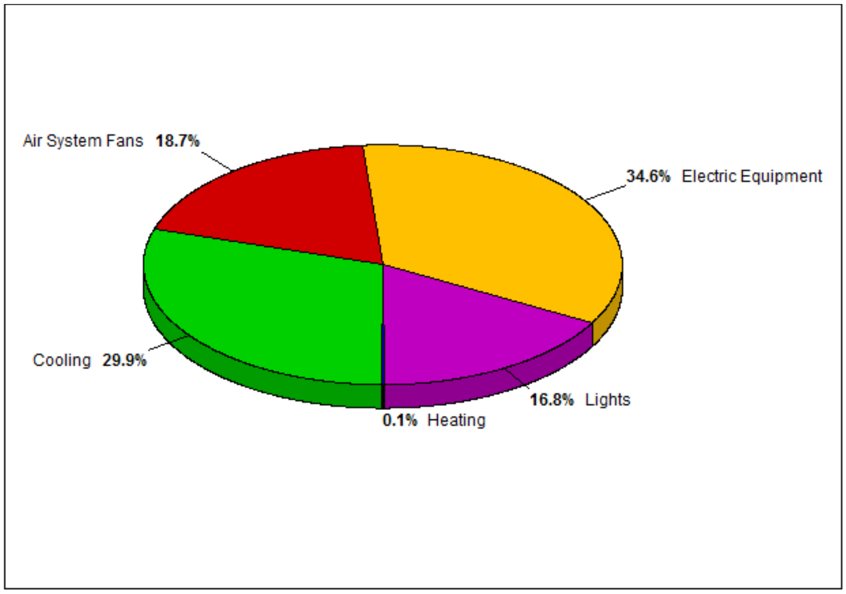


Fig. D9: Results of Simulation 1; Annual Component Costs

D10: Results of Simulation 1; Energy Consumption by Energy Source and System Components

Annual Coil Loads

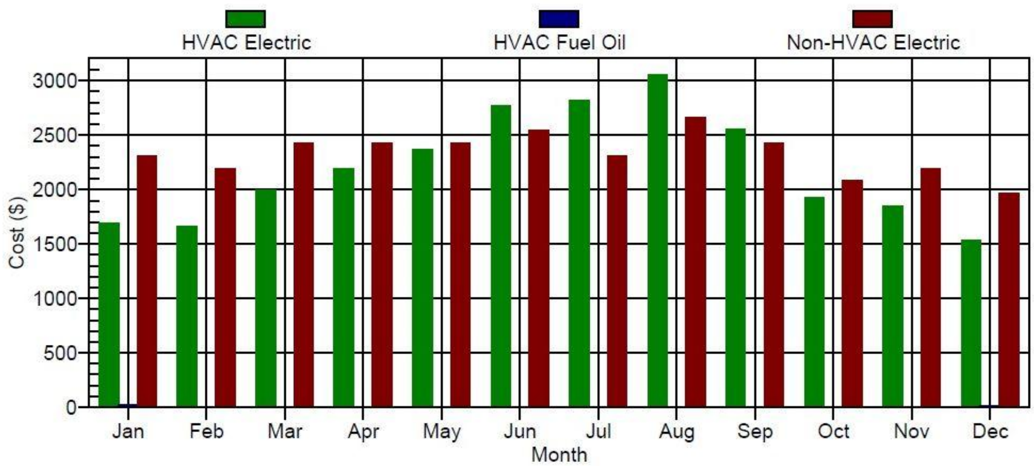
Component	Load (kBTU)	(kBTU/ft²)
Cooling Coil Loads	3,012,123	114.944
Heating Coil Loads	1,323	0.050
Grand Total	**3,013,446**	**114.995**

Energy Consumption by Energy Source

Component	Site Energy (kBTU)	Site Energy (kBTU/ft²)	Source Energy (kBTU)	Source Energy (kBTU/ft²)
HVAC Components				
Electric	1,287,166	49.119	4,597,023	175.425
Natural Gas	0	0.000	0	0.000
Fuel Oil	1,565	0.060	1,565	0.060
Propane	0	0.000	0	0.000
Remote Hot Water	0	0.000	0	0.000
Remote Steam	0	0.000	0	0.000
Remote Chilled Water	0	0.000	0	0.000
HVAC Sub-Total	**1,288,731**	**49.179**	**4,598,588**	**175.484**
Non-HVAC Components				
Electric	1,361,798	51.967	4,863,566	185.596
Natural Gas	0	0.000	0	0.000
Fuel Oil	0	0.000	0	0.000
Propane	0	0.000	0	0.000
Remote Hot Water	0	0.000	0	0.000
Remote Steam	0	0.000	0	0.000
Non-HVAC Sub-Total	**1,361,798**	**51.967**	**4,863,566**	**185.596**
Grand Total	**2,650,530**	**101.146**	**9,462,154**	**361.081**

Energy Consumption by System Component

Component	Site Energy (kBTU)	Site Energy (kBTU/ft²)	Source Energy (kBTU)	Source Energy (kBTU/ft²)
Air System Fans	495,702	18.916	1,770,363	67.558
Cooling	791,486	30.204	2,826,735	107.870
Heating	1,565	0.060	1,565	0.060
Pumps	0	0.000	0	0.000
Cooling Towers	0	0.000	0	0.000
HVAC Sub-Total	**1,288,753**	**49.179**	**4,598,663**	**175.487**
Lights	445,028	16.983	1,589,387	60.652
Electric Equipment	916,789	34.985	3,274,245	124.947
Misc. Electric	0	0.000	0	0.000
Misc. Fuel Use	0	0.000	0	0.000
Non-HVAC Sub-Total	**1,361,817**	**51.968**	**4,863,632**	**185.599**
Grand Total	**2,650,569**	**101.147**	**9,462,295**	**361.086**



HVAC Costs

Month	Electric ($)	Natural Gas ($)	Fuel Oil ($)	Propane ($)	Remote Hot Water ($)	Remote Steam ($)	Remote Chilled Water ($)
January	1,689	0	20	0	0	0	0
February	1,658	0	2	0	0	0	0
March	1,997	0	1	0	0	0	0
April	2,188	0	0	0	0	0	0
May	2,369	0	0	0	0	0	0
June	2,772	0	0	0	0	0	0
July	2,817	0	0	0	0	0	0
August	3,057	0	0	0	0	0	0
September	2,554	0	0	0	0	0	0
October	1,927	0	0	0	0	0	0
November	1,844	0	0	0	0	0	0
December	1,536	0	10	0	0	0	0
Total	**26,407**	**0**	**33**	**0**	**0**	**0**	**0**

Non-HVAC Costs

Month	Electric ($)	Natural Gas ($)	Fuel Oil ($)	Propane ($)	Remote Hot Water ($)	Remote Steam ($)
January	2,309	0	0	0	0	0
February	2,194	0	0	0	0	0
March	2,424	0	0	0	0	0
April	2,424	0	0	0	0	0
May	2,424	0	0	0	0	0
June	2,540	0	0	0	0	0
July	2,309	0	0	0	0	0
August	2,655	0	0	0	0	0
September	2,424	0	0	0	0	0
October	2,078	0	0	0	0	0
November	2,194	0	0	0	0	0
December	1,963	0	0	0	0	0
Total	**27,938**	**0**	**0**	**0**	**0**	**0**

Fig. D11: Results of Simulation 1; Monthly Energy Costs

D12: Simulation 1 – Positively Pressurized Building

Simulation 1						
AHU	SA CFM	OSA CFM	Max Zone Dry Bulb Temperature (^{O}F)	Resulting RH (%)	Cooling Coil Load (Tons)	Heating Coil Load (MBH)
1	2,202	55	84.1	38	7.7	2.0
2	931	15	83.6	36	3.3	0.0
3	1,372	72	81.4	47	5.1	0.0
4	3,000	37	81.8	44	9.1	0.0
5	795	88	74.5	42	3.2	0.6
6	2,529	311	76.2	71	4.4	8.0
7	1,488	43	99.4	28	8.0	5.0
8	1,658	911	82.3	48	10.1	39.2
9	2,230	30	82.0	42	5.4	4.4
10	1,487	128	82.1	39	5.2	8.2
11	1,301	107	85.6	35	5.0	5.3
12	1,115	64	85.6	37	4.2	4.4
13	1,558	16	88.4	32	6.3	3.9
14	1,685	140	77.5	49	4.6	4.6
15	743	79	98.8	20	3.6	0.4
16	1,858	115	86.6	46	9.9	6.4
17	1,672	123	78.8	53	5.4	5.8
18	1,672	255	77.5	49	6.1	13.3
	29,296	2,589			106.6	111.5

D13: Simulation 2 – Non-Pressurized Building

Simulation 2						
AHU	SA CFM	OSA CFM	Max Zone Dry Bulb Temperature (^{O}F)	Resulting RH (%)	Cooling Coil Load (Tons)	Heating Coil Load (MBH)
1	2,202	35	84.1	38	7.6	1.2
2	931	10	83.6	36	3.3	0.0
3	1,372	46	81.4	47	5.0	0.0
4	3,000	24	81.8	44	9.1	0.0
5	795	56	74.5	42	3.0	0.0
6	2,529	198	76.2	71	4.0	2.5
7	1,488	27	99.4	27	8.0	3.6
8	1,658	581	82.3	48	8.9	23.2
9	2,230	19	82.0	42	5.4	4.1
10	1,487	82	82.1	38	5.0	6.9
11	1,301	68	85.9	35	4.9	3.2
12	1,115	41	85.6	34	4.1	3.0
13	1,558	10	88.5	32	6.2	3.5
14	1,685	89	77.5	48	4.4	2.5
15	743	50	98.8	20	3.5	0.0
16	1,858	73	86.6	46	9.8	4.3
17	1,672	78	78.8	53	5.2	3.1
18	1,672	163	77.5	49	5.6	9.6
	29,296	1,652			103.0	70.7

D14: Simulation 3 - Negatively Pressurized Building

Simulation 3						
AHU	SA CFM	OSA CFM	Max Zone Dry Bulb Temperature (^{O}F)	Resulting RH (%)	Cooling Coil Load (Tons)	Heating Coil Load (MBH)
1	2,202	21	84.2	40	8.0	6.2
2	931	6	83.6	36	3.3	0.0
3	1,372	28	81.7	49	5.2	2.8
4	3,000	14	82.0	45	9.4	3.9
5	795	34	75.1	41	2.9	0.0
6	2,529	120	76.2	71	3.8	0.0
7	1,488	17	99.4	27	8.0	3.2
8	1,658	352	82.3	47	8.1	12.0
9	2,230	12	82.2	43	5.6	6.4
10	1,487	49	82.3	38	4.9	4.4
11	1,301	41	85.9	35	4.8	2.0
12	1,115	25	85.6	34	4.0	2.2
13	1,558	6	88.5	32	6.2	3.2
14	1,685	54	77.5	48	4.2	0.8
15	743	31	97.6	26	3.8	5.8
16	1,858	44	86.6	9.7	9.7	3.1
17	1,672	48	78.8	53	5.1	1.5
18	1,672	98	77.5	49	5.3	6.4
	29,296	1,000			102.3	63.9

D15: Simulation 4 - Originally Designed System

Simulation 4						
AHU	SA CFM	OSA CFM	Max Zone Dry Bulb Temperature (^{O}F)	Resulting RH (%)	Cooling Coil Load (Tons)	Heating Coil Load (MBH)
1	3,000	2,100	78.7	47	17.3	102.6
2	1,000	100	82.0	38	3.7	3.3
3	1,200	125	84.0	44	5.1	1.4
4	3,725	250	78.8	49	10.5	9.5
5	650	100	77.7	37	3.2	1.0
6	2,475	275	76.4	71	4.3	6.2
7	1,600	125	98.0	29	8.5	8.6
8	1,600	175	82.8	47	7.4	2.7
9	2,400	150	81.0	44	6.0	10.1
10	1,600	100	80.9	40	5.2	7.4
11	1,400	125	84.5	37	5.2	6.2
12	1,200	125	84.0	36	4.6	7.2
13	1,800	150	85.8	35	7.1	10.2
14	1,800	200	76.6	50	4.9	7.5
15	800	75	97.2	22	3.6	0.6
16	2,000	155	85.4	47	10.2	8.3
17	1,800	175	77.7	55	5.7	8.9
18	1,800	150	76.3	51	5.6	8.5
	31,850	4,655			118.1	210.2

D16: Simulation 5 - HAP 4.5 Recommended System

Simulation 5						
AHU	SA CFM	OSA CFM	Max Zone Dry Bulb Temperature (^{O}F)	Resulting RH (%)	Cooling Coil Load (Tons)	Heating Coil Load (MBH)
1	5,190	1,254	71.5	60	14.9	58.0
2	2,292	436	71.5	62	5.8	20.1
3	2,827	555	71.5	64	8.0	22.6
4	5,779	1,332	71.8	59	17.0	60.3
5	1,264	389	71.7	55	4.9	15.3
6	1,654	458	71.5	60	5.9	14.6
7	8,091	903	71.7	62	16.6	47.6
8	3,386	923	71.7	63	12.1	39.1
9	4,147	254	71.6	57	7.5	15.5
10	3,430	220	71.5	59	6.5	13.0
11	3,587	291	71.5	60	7.1	13.9
12	3,186	261	71.5	60	6.1	14.3
13	5,086	602	71.6	61	10.8	33.0
14	2,715	207	71.5	59	5.5	6.8
15	3,286	131	71.5	57	5.3	3.4
16	5,294	823	71.8	65	15.2	40.8
17	2,954	817	71.5	64	9.5	39.4
18	2,830	810	71.6	61	9.4	39.7
	66,998	10,666			168.1	497.4

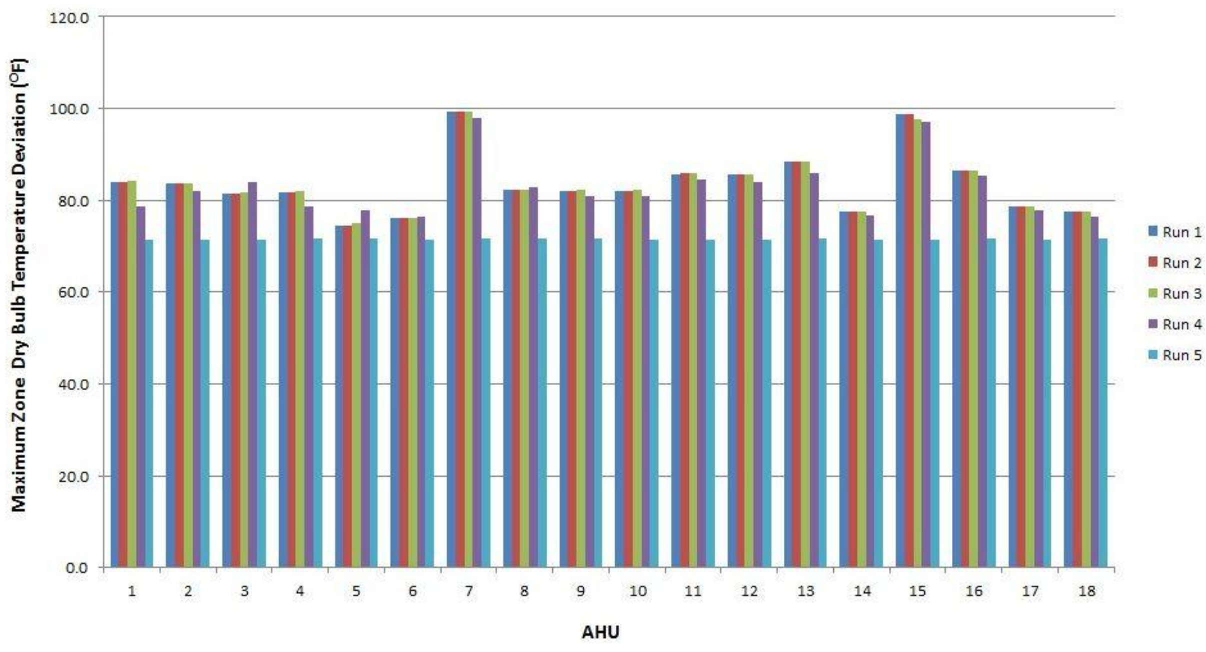


Fig. D17: Comparison of Maximum Zone Dry Bulb Temperatures for Different Runs

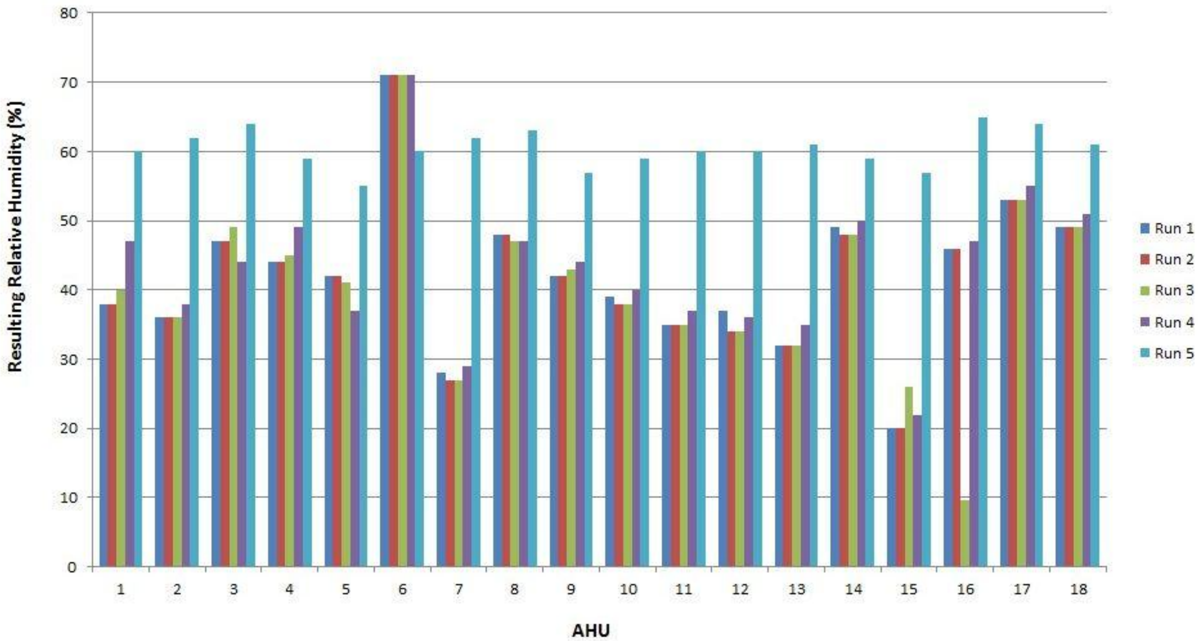


Fig. D18: Comparison of Resulting Relative Humidities for Different Runs

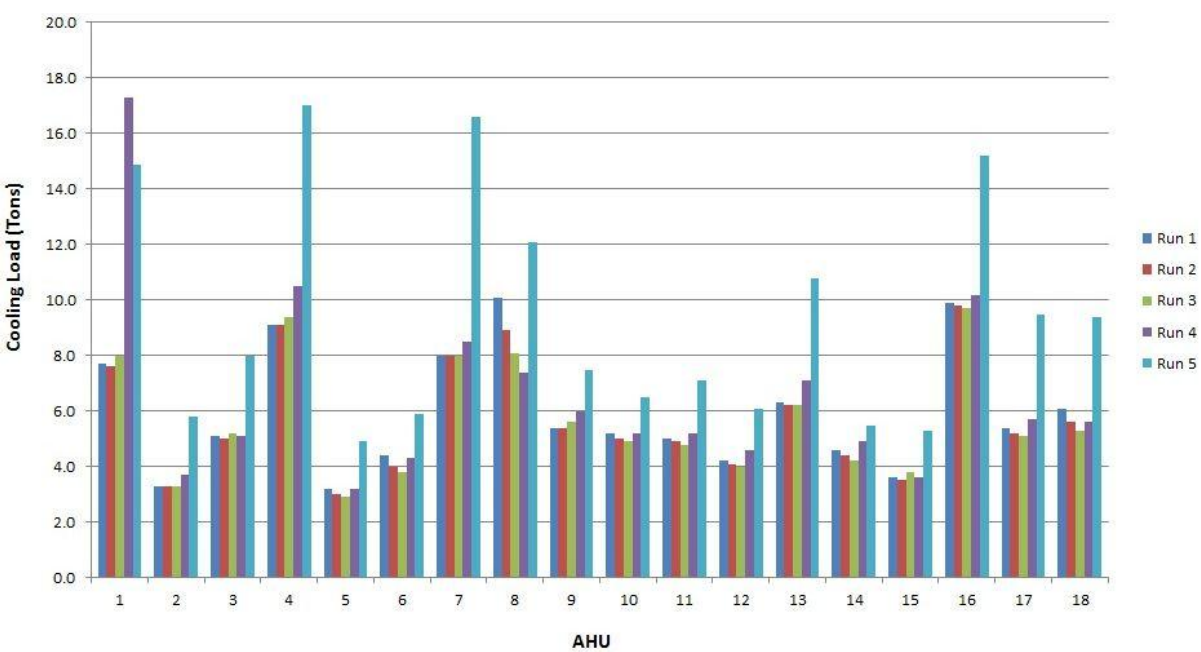


Fig. D19: Comparison of Cooling Loads for Different Runs

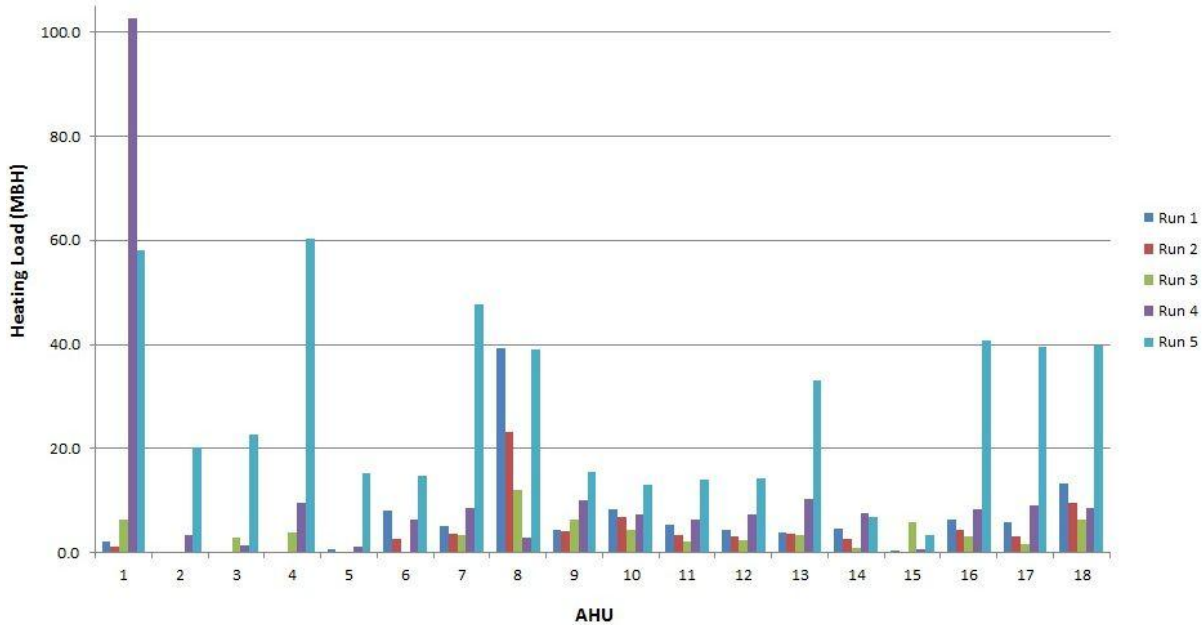


Fig. D20: Comparison of Heating Loads for Different Runs

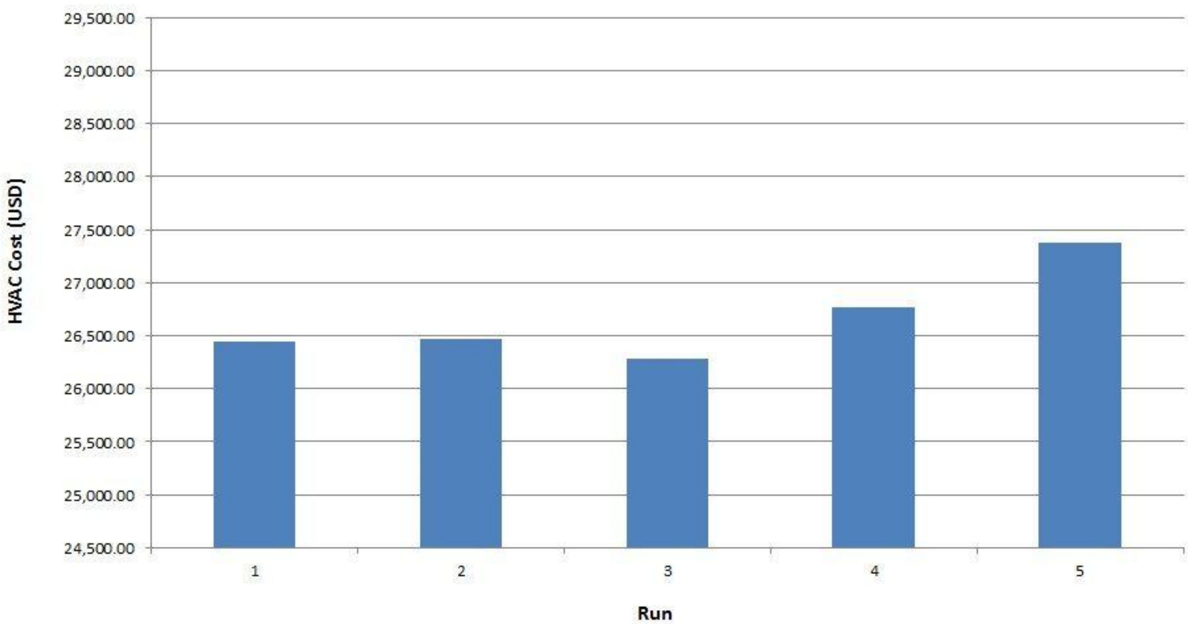


Fig. D21: Comparison of Annual HVAC Costs

GLOSSARY OF SOME TERMS IN HAP 4.5

(a) **Activity Level**: Heat gain from people varies depending on the activity being performed in the space. HAP 4.5 offers the seven standard activity levels listed in the table below plus a "user-defined" option. Choose the desired activity level from the drop-down list.

When one of the standard activity levels is chosen, the corresponding sensible and latent heat gains shown in the table below are used automatically. In order to directly specify sensible and latent heat gains for people, the "User-Defined" activity level option has to be chosen.

Table G1: Activity Level Values

Activity Level	Sensible Heat Gain (BTU/h person)	Latent Heat Gain (BTU/h person)	Sensible Heat Gain (W person)	Latent Heat Gain (W/person)
Seated At Rest	230	120	67.4	35.2
Office Work	245	205	71.8	60.1
Sedentary Work	280	270	82.1	79.1
Medium Work	295	455	86.5	133.4
Heavy Work	525	925	153.9	271.1
Dancing	305	545	89.4	159.7
Athletics	710	1090	208.1	319.4

(b) **Ballast Multiplier**: For fluorescent lights, power is used to drive both the bulb and a ballast starter device. HAP 4.5 computes the total power draw for the lighting fixture by multiplying lamp wattage by the ballast multiplier. Ballast multipliers typically range between 1.00 and 2.00. Common values are in the 1.00 to 1.25 range. When incandescent lighting fixtures are used, the ballast multiplier should be specified as 1.00.

(c) **Base Ventilation Rate**: It defines the minimum ventilation airflow rate for ‘Demand Controlled Ventilation’ control as a percentage of the design airflow rate. The base ventilation rate accounts for non-occupant sources of pollutants such as those from materials, carpeting or furnishing. It typically ranges from 15% to 50% depending on the application. Common rule of thumb values are in the 20% to 30% range.

(d) **Building**: A Building is the container holding all the HVAC and non-HVAC systems for one design scenario being studied in an energy analysis. Taken literally, a building represents one individual structure. However, the definition of a building is flexible. It can represent a portion of an actual building such as a renovation or addition. It can also represent a group of structures. For example, a "building" could represent a campus in which all the structures are served by a common set of plant equipment.

(e) **Coil Bypass Factor**: It is used to evaluate dehumidification occurring at the cooling coil. In general, the bypass factor is a measure of the approach to the apparatus dew point

(ADP) for air flowing through the coil. The smaller the bypass factor, the closer the outlet air approaches the ADP state.

The coil bypass factor can be obtained from product literature when modeling specific equipment. In most system design applications, however, the HVAC equipment has not yet been selected. In such a situation, specify a bypass factor that is generally representative of the type of equipment you intend to select.

(f) **Damper Leak Rate**: It defines how much air leaks through dampers when they are closed and the system is running. Leakage is defined as a percentage of the design outdoor ventilation airflow rate. If dampers are open during the unoccupied period, this input is not used.

(g) **Direct Exhaust Air**: These inputs describe air directly exhausted from the zone by devices such as laboratory hoods, kitchen hoods and toilet exhausts.

(h) **Diversity Factor**: The diversity factor is used to change lighting and occupant loads for the two stages of system design calculations. When calculating required zone airflow rates, HAP 4.5 calculates lighting and occupant loads according to the user's original space and schedule specifications. When simulating system operation to determine

cooling and heating coil loads, the program provides the option of adjusting lighting and people loads to lower levels using the diversity factor.

When entering diversity factors, 100% means that people and lighting loads will be used as originally specified in space inputs. A 0% diversity factor means that people and lighting loads will be eliminated completely.

(i) **Hydronic Sizing Specifications**: This section of the ‘System Sizing Data’ provides specifications for sizing water flow rates in hydronic cooling and heating coils in the system. The section contains two input items:

(1) **Chilled Water ΔT**: It defines the temperature difference between water leaving and entering a cooling coil. It is used together with the peak coil load to determine the required water flow rate for the coil. Note that this value is used to size water flow rate for all cooling coils whose cooling source is "chilled water". When a system does not contain hydronic cooling coils, this input is not used.

(2) **Hot Water ΔT**: It defines the temperature difference between water entering and leaving a heating coil. It is used together with the peak coil load to determine the required water flow rate for the coil. Note that this value is used to size water flow rate for all heating coils in the system whose heat source is "hot water". When a system does not contain hot water heating coils, this input is not used.

(j) **Infiltration**: Infiltration results from the leakage of outdoor air into the space. This typically occurs because of leakage around windows and doors, and leakage from the opening and closing of doors in the space. Infiltration data is used to calculate the sensible and latent infiltration loads for the space.

(k) **Outdoor Air CO_2 Level**: It defines the average concentration of carbon dioxide in outside air. It is not used in Proportional control calculations. However, HAP 4.5 performs a CO_2 balance calculation for all systems and displays the results on the System Psychrometrics report to allow users to examine CO_2 levels in the occupied zones. The 'Outdoor Air CO_2 Level' is required for this calculation and therefore this input is required for all types of ventilation control. 400 parts per million (ppm) is a rule of thumb default for the outdoor CO_2 level.

(l) **Plant**: A Plant is the equipment and controls which provide chilled water to cooling coils, or hot water or steam to heating coils in one or more air systems. Examples include chiller plants, hot water boiler plants and steam boiler plants.

(m) **Reclaim**: It defines whether the device reclaims sensible heat only or both sensible and latent heat. The "Sensible Heat" option should be used for devices such as air-to-air heat exchangers, which transfer only sensible heat between outdoor and exhaust air streams.

The "Sensible & Latent Heat" option is used for devices such as desiccant wheels which transfer both sensible heat and moisture between air streams.

(n) **Setpoint**: It specifies the temperatures at which a temperature controlling devise such as a thermostat can be set. Once a set point is reached, the temperature control devise triggers to bring a desired heat transfer process into action.

(o) **Sum of Space OA Airflows**: This is a method that calculates the design ventilation airflow by summing the space outdoor airflow requirements for all spaces served by the system. Certain ventilation standards and codes use this approach. This approach is also typically used when the building is not subject to a ventilation standard or code.

(p) **Unoccupied Damper Position**: It is an input to HAP 4.5 that specifies whether outdoor air dampers are open during the unoccupied equipment operating period. When the "Open" item is selected ventilation airflow will be controlled in the same way it is in the occupied period whenever the system runs during unoccupied hours. When the "Closed" item is selected dampers will be closed and only the specified damper leakage will occur when the system runs during unoccupied hours.